

US011207631B2

(12) **United States Patent**
Li et al.

(10) **Patent No.:** **US 11,207,631 B2**
(45) **Date of Patent:** ***Dec. 28, 2021**

(54) **SYSTEM AND METHOD FOR IMPROVING MASS AIR FLOW SIGNAL QUALITY**

(71) Applicant: **CUMMINS FILTRATION IP, INC.**,
Columbus, IN (US)

(72) Inventors: **Miao Li**, McFarland, WI (US); **Peter K. Herman**, Stoughton, WI (US); **John C. Lukasavitz**, Flushing, MI (US); **Abhijit Shimpi**, Columbus, IN (US); **Gregory W. Hoverson**, Columbus, IN (US); **Thomas J. Braun**, Stoughton, WI (US); **Robert A. Bannister**, Stoughton, WI (US)

(73) Assignee: **CUMMINS FILTRATION IP, INC.**,
Columbus, IN (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 181 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **16/552,409**

(22) Filed: **Aug. 27, 2019**

(65) **Prior Publication Data**
US 2019/0381442 A1 Dec. 19, 2019

Related U.S. Application Data

(63) Continuation of application No. 15/304,322, filed as application No. PCT/US2015/025582 on Apr. 13, 2015, now Pat. No. 10,507,417.
(Continued)

(51) **Int. Cl.**
B01D 35/02 (2006.01)
F02M 35/10 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC **B01D 46/0049** (2013.01); **B01D 46/522** (2013.01); **F02M 35/021** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC B01D 46/0049; B01D 46/522; B01D 2265/04; B01D 2279/60; G01F 15/00;
(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,909,815 A 3/1990 Meyer
5,354,460 A * 10/1994 Kearney B01D 3/008
210/198.2
(Continued)

FOREIGN PATENT DOCUMENTS

WO WO-2015/160709 A1 10/2015

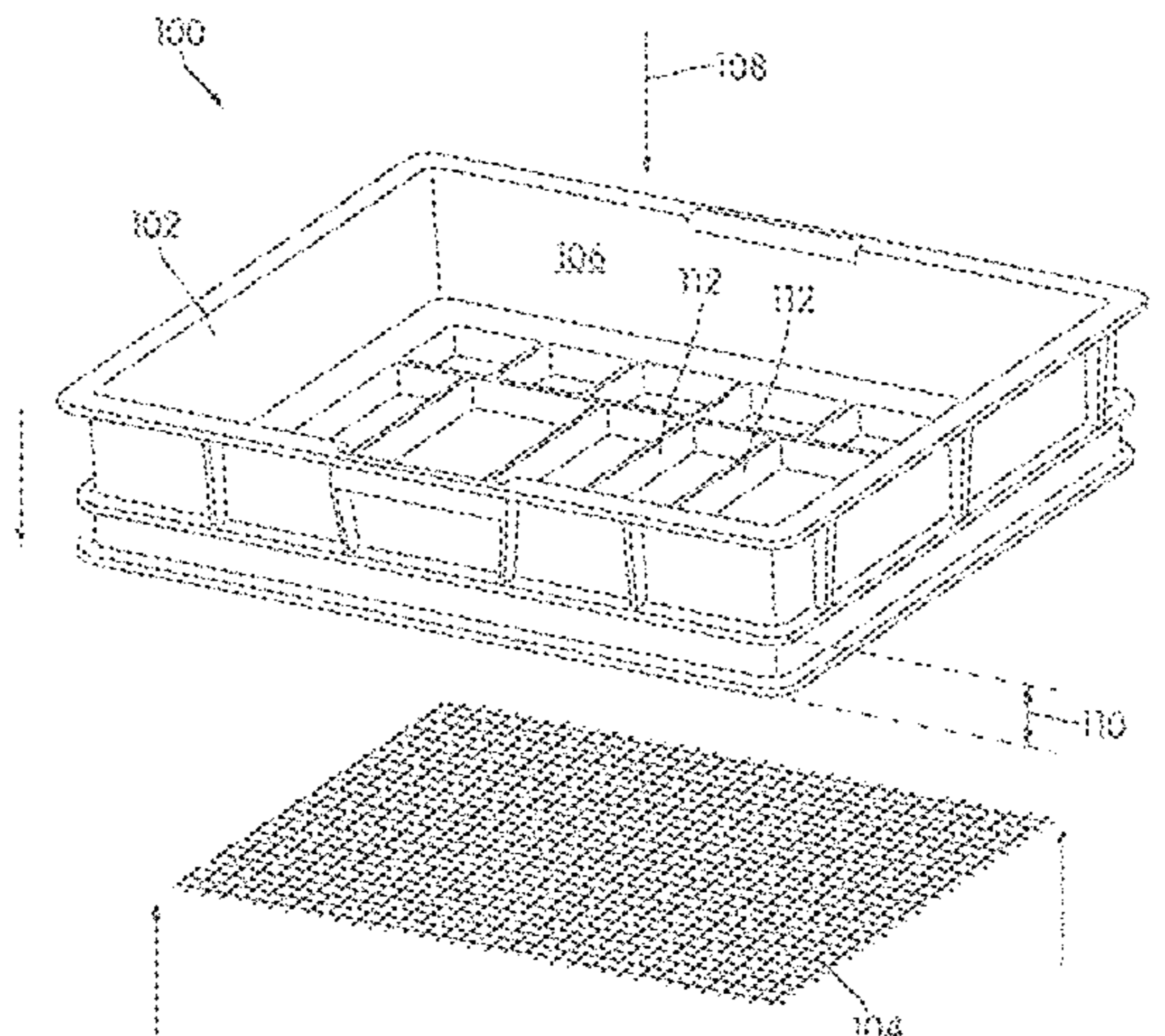
OTHER PUBLICATIONS

Final Office Action for U.S. Appl. No. 15/304,322 dated May 21, 2019, 8 pages.
(Continued)

Primary Examiner — Frank M Lawrence, Jr.
(74) *Attorney, Agent, or Firm* — Foley & Lardner LLP

(57) **ABSTRACT**

A filter assembly includes a conditioning device that conditions a flow of air upstream of a mass air flow sensor. The filter assembly includes a support frame. The filter assembly further includes a filter media coupled to the support frame, the filter media having a dirty side configured to receive a stream of air and a clean side configured to output a stream of air that has been filtered through the filter media. The filter assembly includes a conditioning device coupled to the support frame, the conditioning device positioned in a downstream direction from the clean side of the filter media
(Continued)



with respect to the stream of air, the conditioning device offset from the clean side of the filter media by a separation distance.

15 Claims, 25 Drawing Sheets

Related U.S. Application Data

(60) Provisional application No. 61/980,997, filed on Apr. 17, 2014.

(51) **Int. Cl.**

B01D 46/00 (2006.01)
G01F 15/12 (2006.01)
F02M 35/02 (2006.01)
G01F 15/00 (2006.01)
B01D 46/52 (2006.01)
F02M 35/024 (2006.01)

(52) **U.S. Cl.**

CPC .. **F02M 35/0207** (2013.01); **F02M 35/02416** (2013.01); **F02M 35/02466** (2013.01); **F02M 35/10386** (2013.01); **G01F 15/00** (2013.01); **G01F 15/125** (2013.01); **B01D 2265/04** (2013.01); **B01D 2279/60** (2013.01); **F02M 35/02491** (2013.01); **F02M 35/10249** (2013.01)

(58) **Field of Classification Search**

CPC **G01F 15/125**; **F02M 35/0207**; **F02M 35/021**; **F02M 35/02416**; **F02M 35/02466**; **F02M 35/02491**; **F02M 35/10249**; **F02M 35/10386**
 USPC 55/315, 482, 492, 497, 511
 See application file for complete search history.

(56)

References Cited

U.S. PATENT DOCUMENTS

5,573,811 A 11/1996 Townsley
 5,631,415 A 5/1997 Igarashi et al.

6,047,903 A 4/2000 Meyer
 6,112,590 A 9/2000 Rilling
 6,145,544 A 11/2000 Dutertre et al.
 6,156,089 A 12/2000 Stemmer et al.
 6,199,434 B1 3/2001 Cornil et al.
 6,464,761 B1 10/2002 Bugli
 6,736,871 B1 5/2004 Green et al.
 6,764,533 B2 7/2004 Lobiondo, Jr.
 7,097,694 B1 8/2006 Jaroszczyk et al.
 7,294,179 B2* 11/2007 Kim B01D 53/0446
 96/121
 7,531,029 B2 5/2009 Hoke et al.
 8,062,403 B2 11/2011 Goode
 9,827,524 B2 11/2017 Lukasavitz
 10,507,417 B2* 12/2019 Li B01D 46/522
 2004/0055570 A1 3/2004 Bielicki et al.
 2004/0255660 A1 12/2004 Abdolhosseini et al.
 2006/0180389 A1 8/2006 Cheng et al.
 2007/0297285 A1* 12/2007 Cross B01F 5/06
 366/340
 2009/0120046 A1 5/2009 Huff
 2010/0186353 A1 7/2010 Ackermann et al.
 2010/0269583 A1 10/2010 Jasnie
 2013/0160651 A1* 6/2013 Mani B01D 53/04
 96/132
 2019/0381442 A1 12/2019 Li et al.

OTHER PUBLICATIONS

International Search Report and Written Opinion Issued for PCT/US2015/025582, dated Jul. 2, 2015, 8 Pages.
 International Search Report and Written Opinion issued for PCT/US2017/054902, dated Dec. 11, 2017, 16 pages.
 ISO 5167-6 "Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full—Part 6: Wedge meters," International Organization for Standardization, 20 pages (2019).
 Non-Final Office Action for U.S. Appl. No. 15/304,322 dated Jan. 11, 2019.
 Notice of Allowance for U.S. Appl. No. 15/304,322 dated Aug. 14, 2019.
 Non-Final Office Action issued for U.S. Appl. No. 16/342,265, dated Apr. 19, 2021, 31 pages.

* cited by examiner

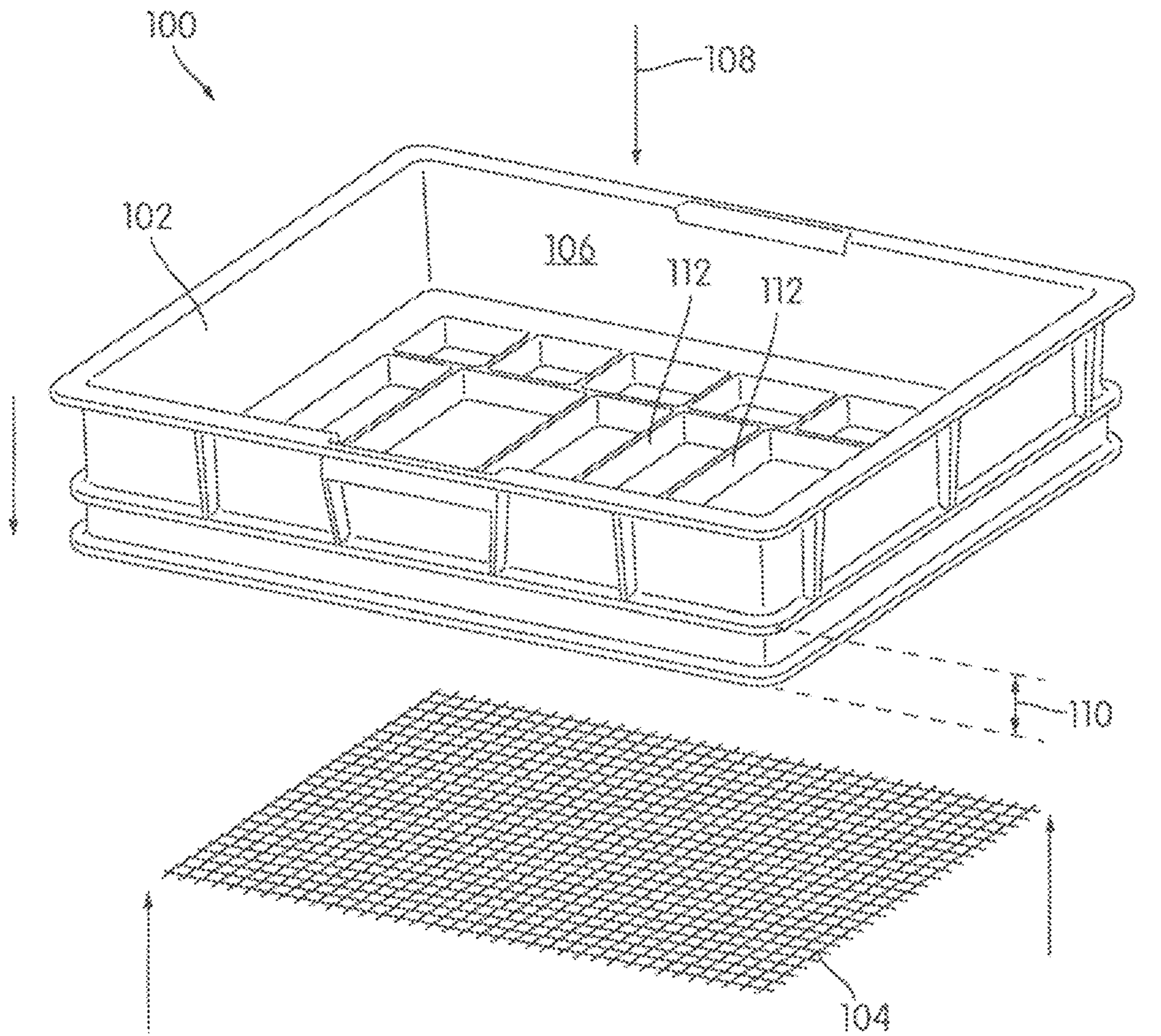


FIG. 1

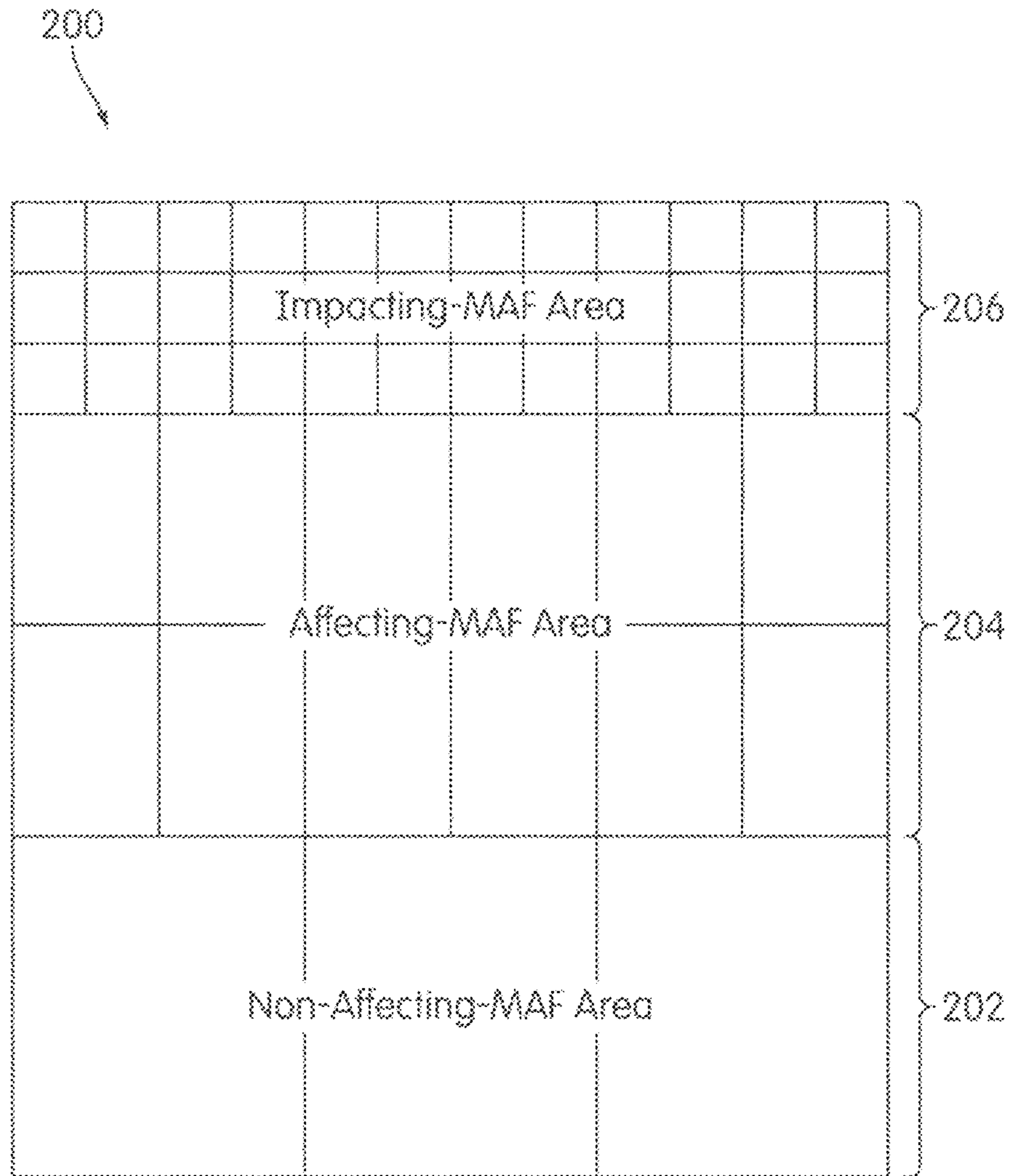


FIG. 2

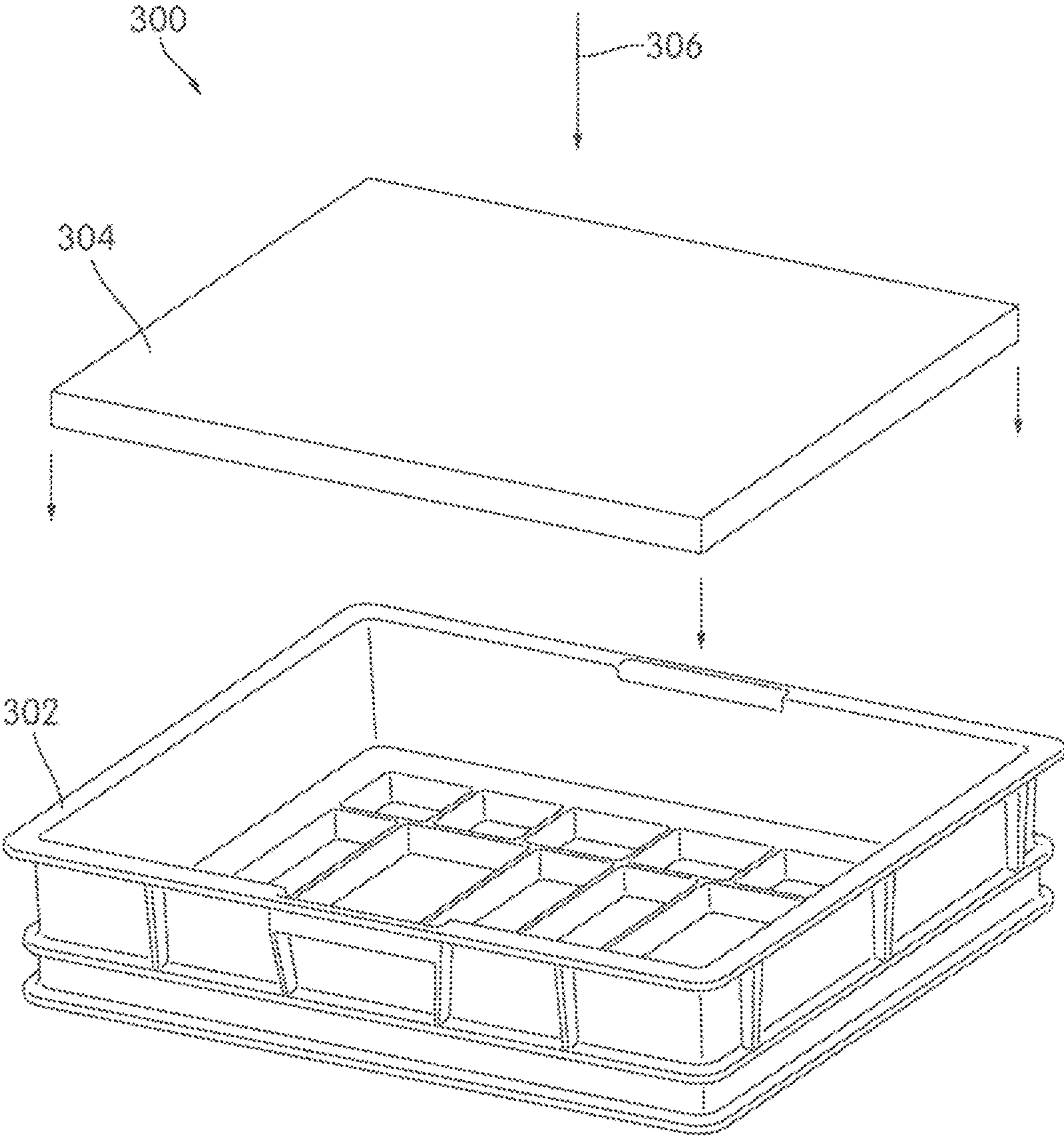


FIG. 3

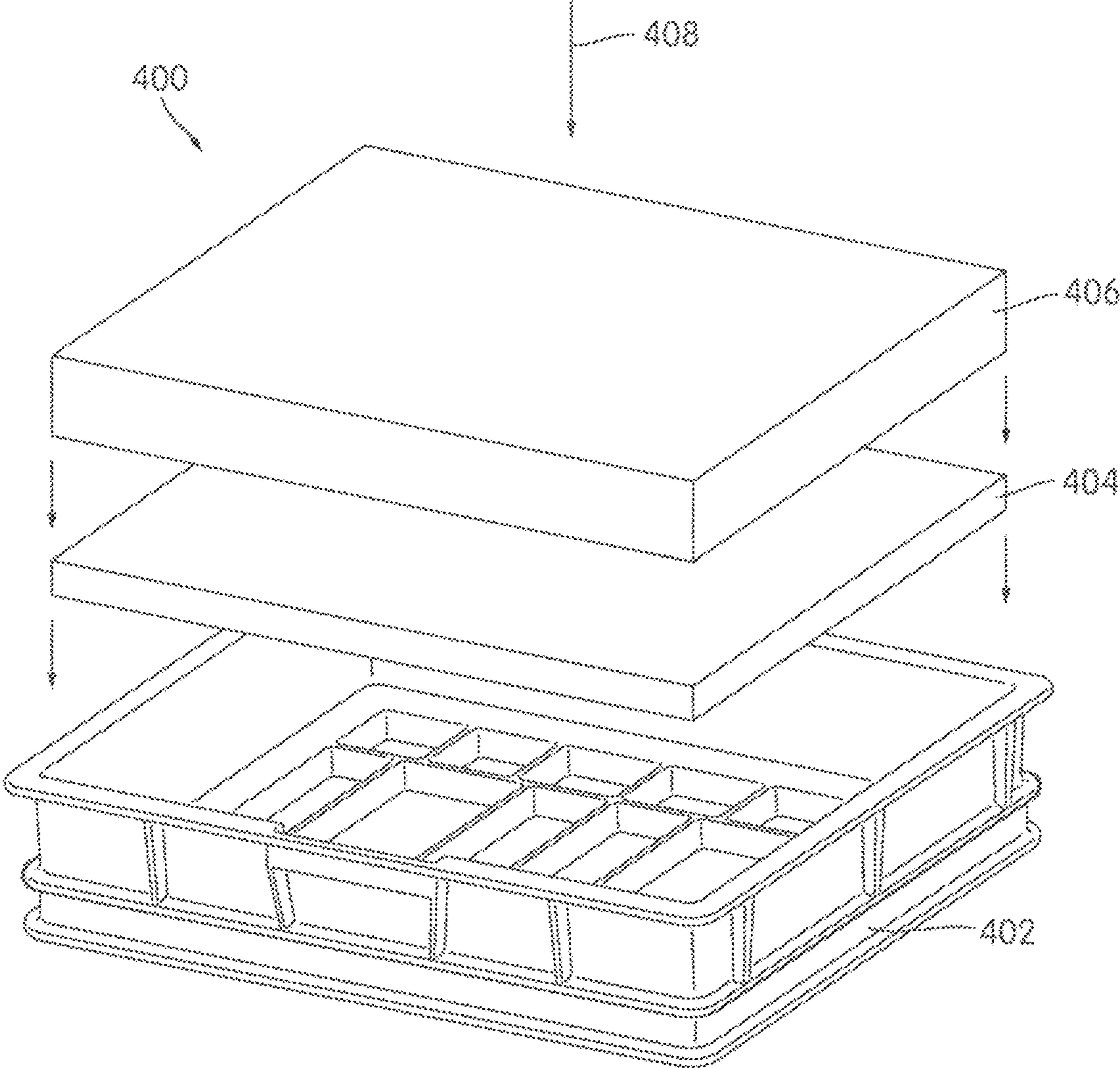


FIG. 4

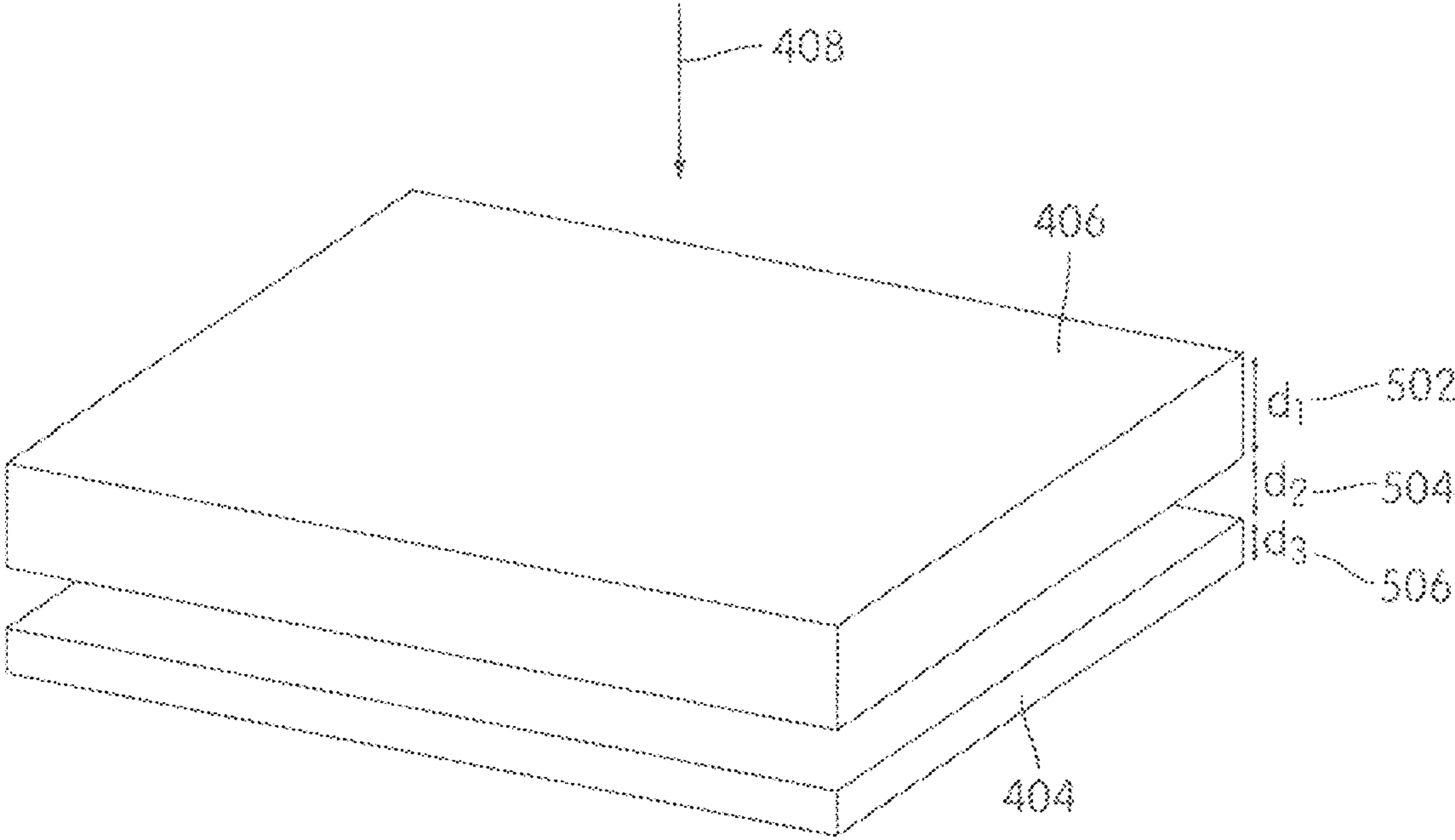


FIG. 5

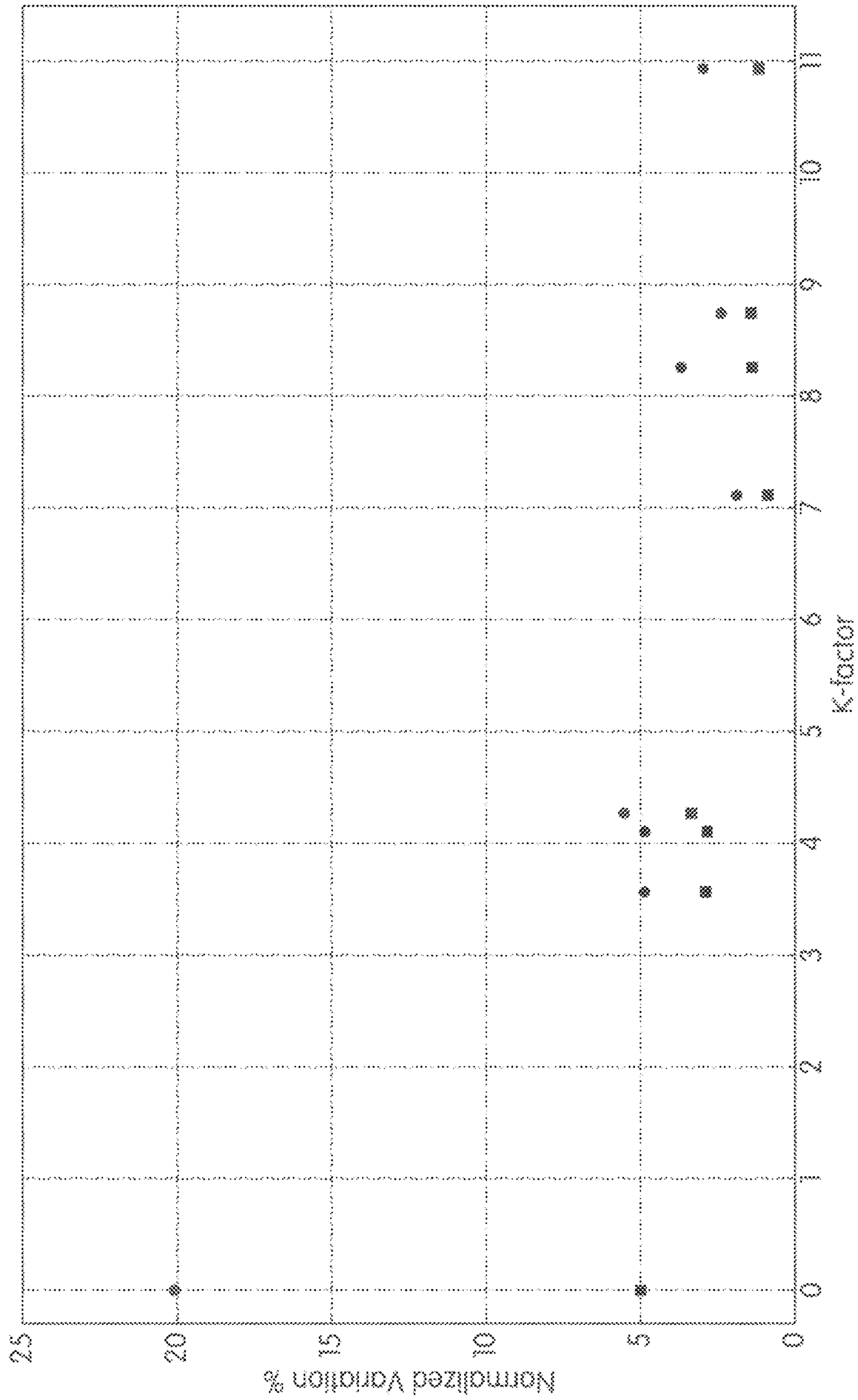


FIG. 6

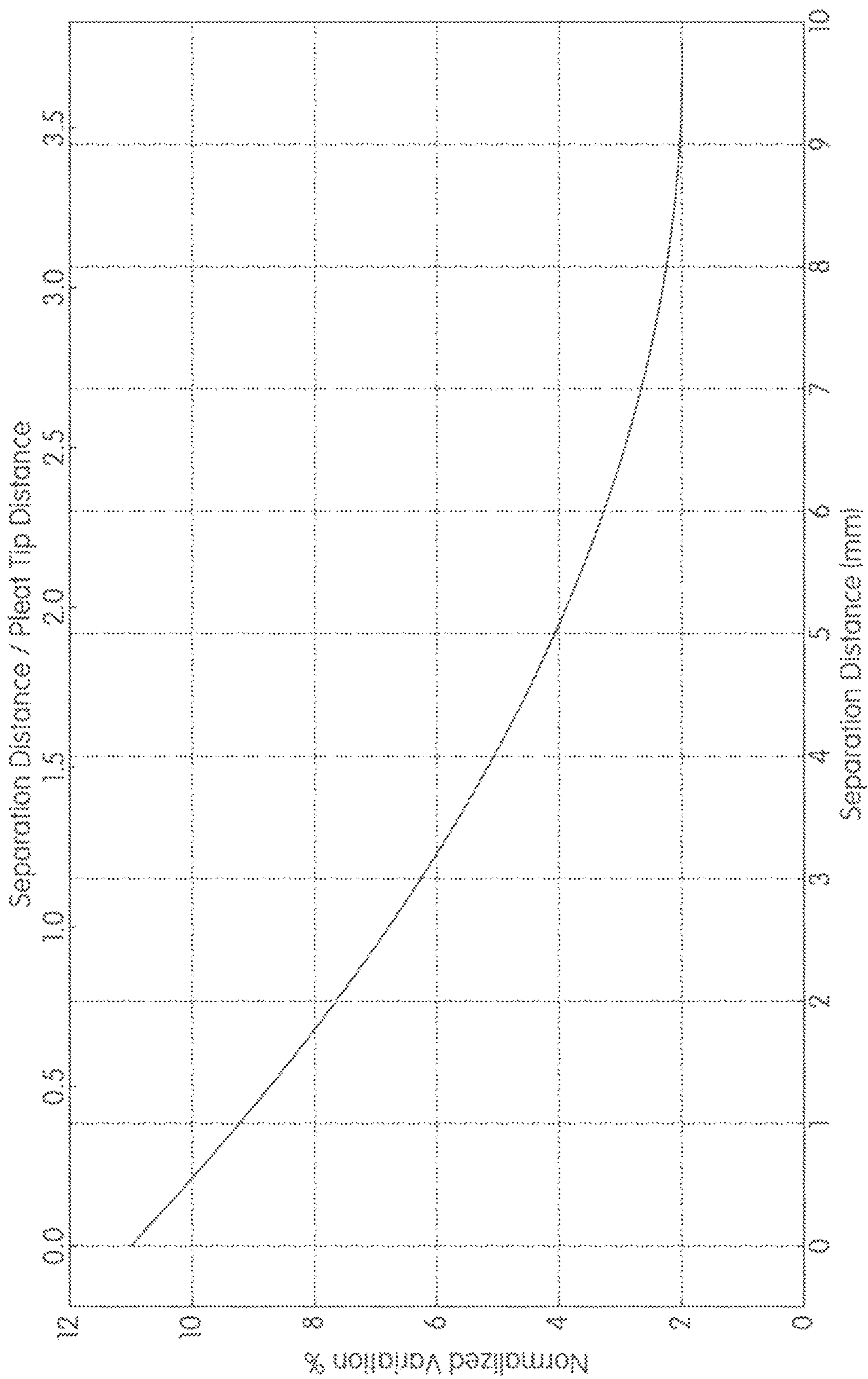


FIG. 7

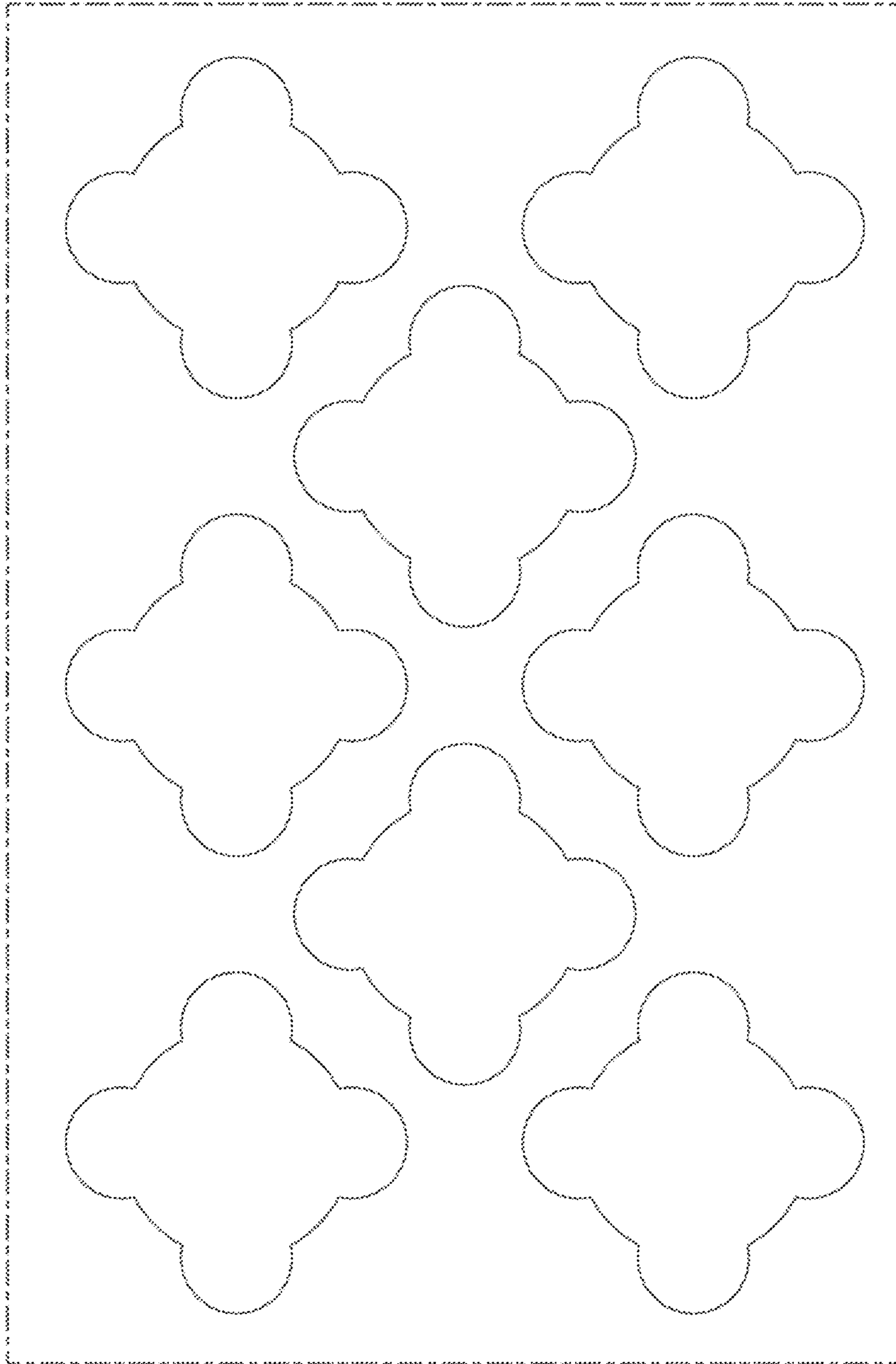


FIG. 8A

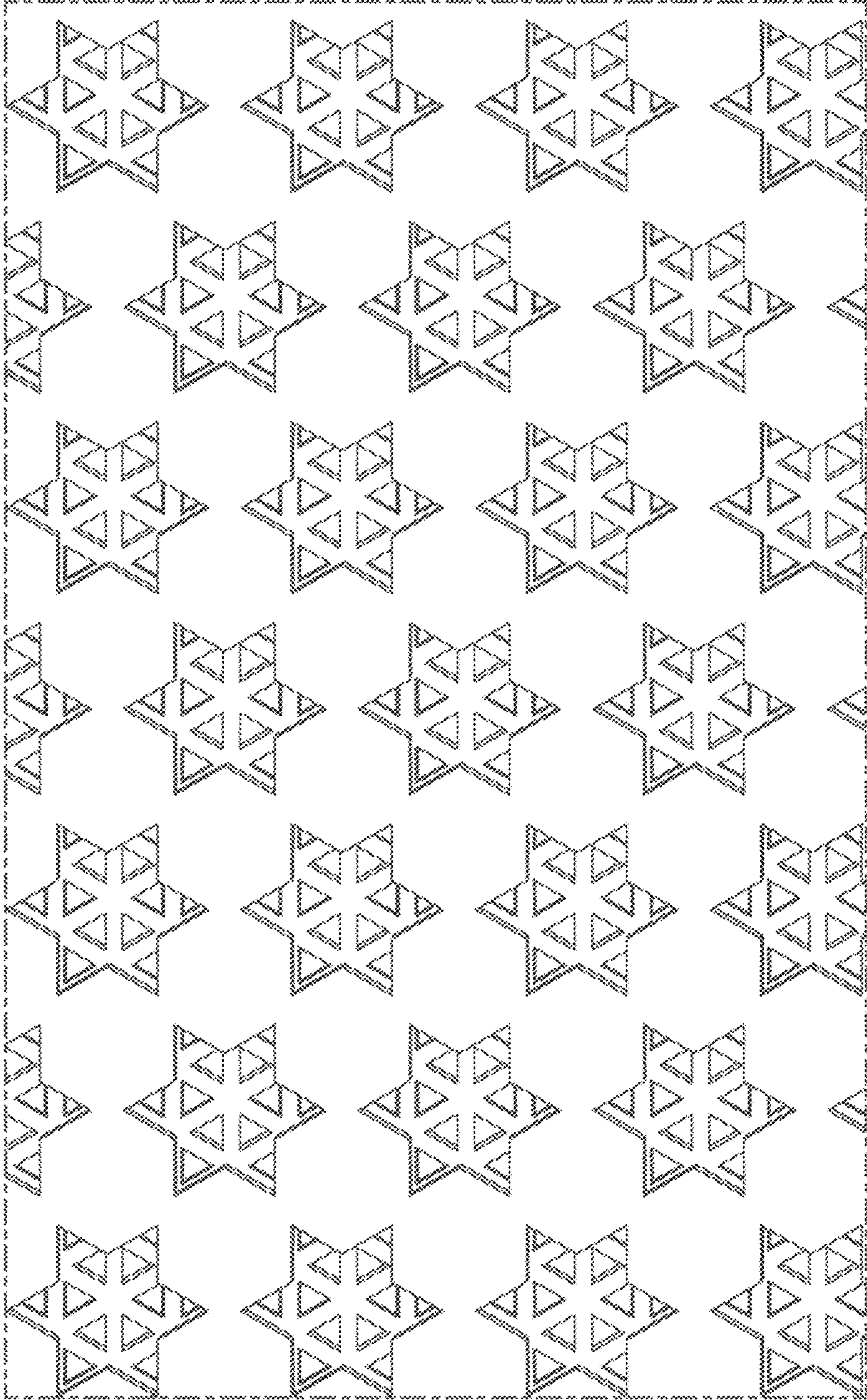


FIG. 8B

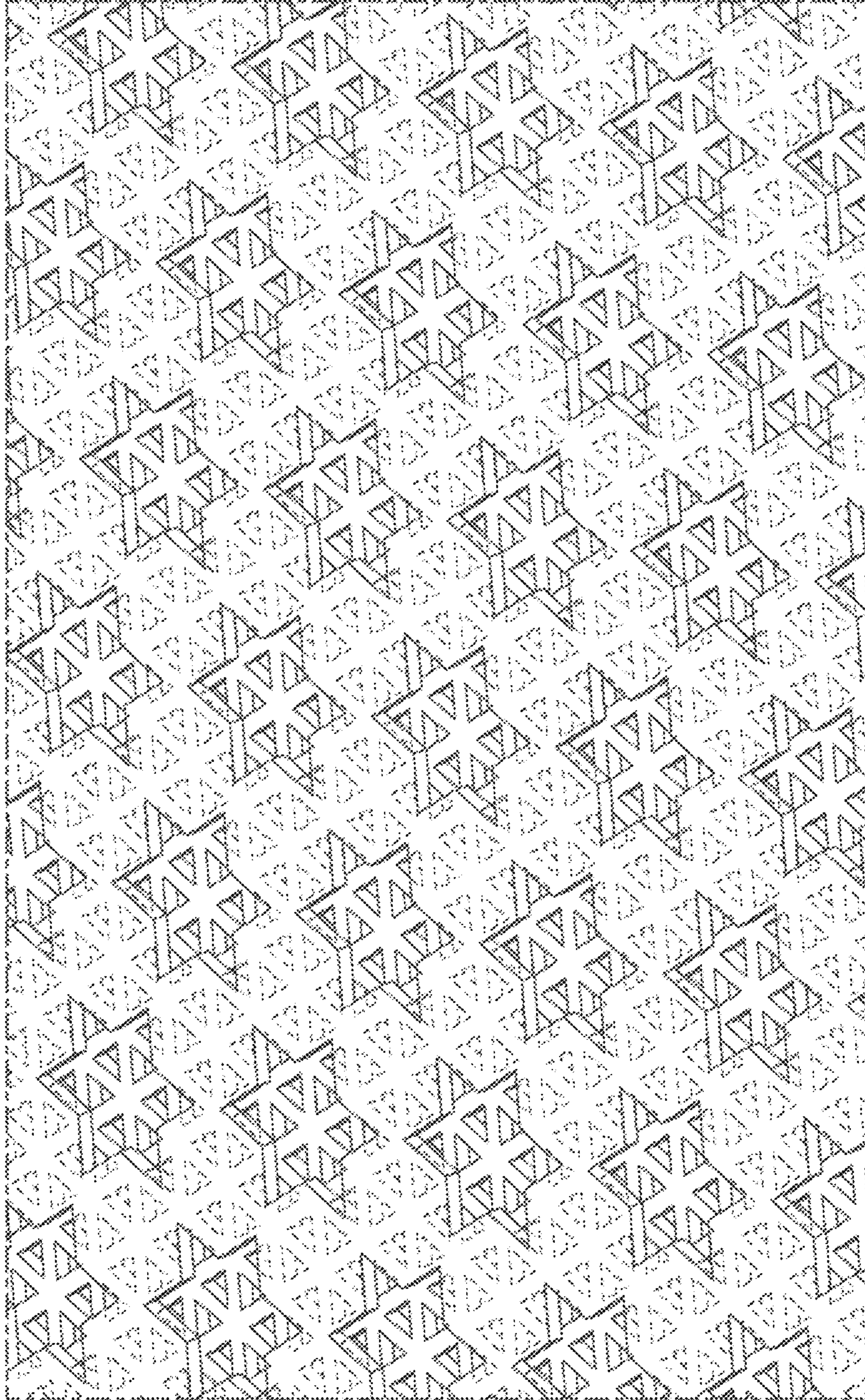


FIG. 8C

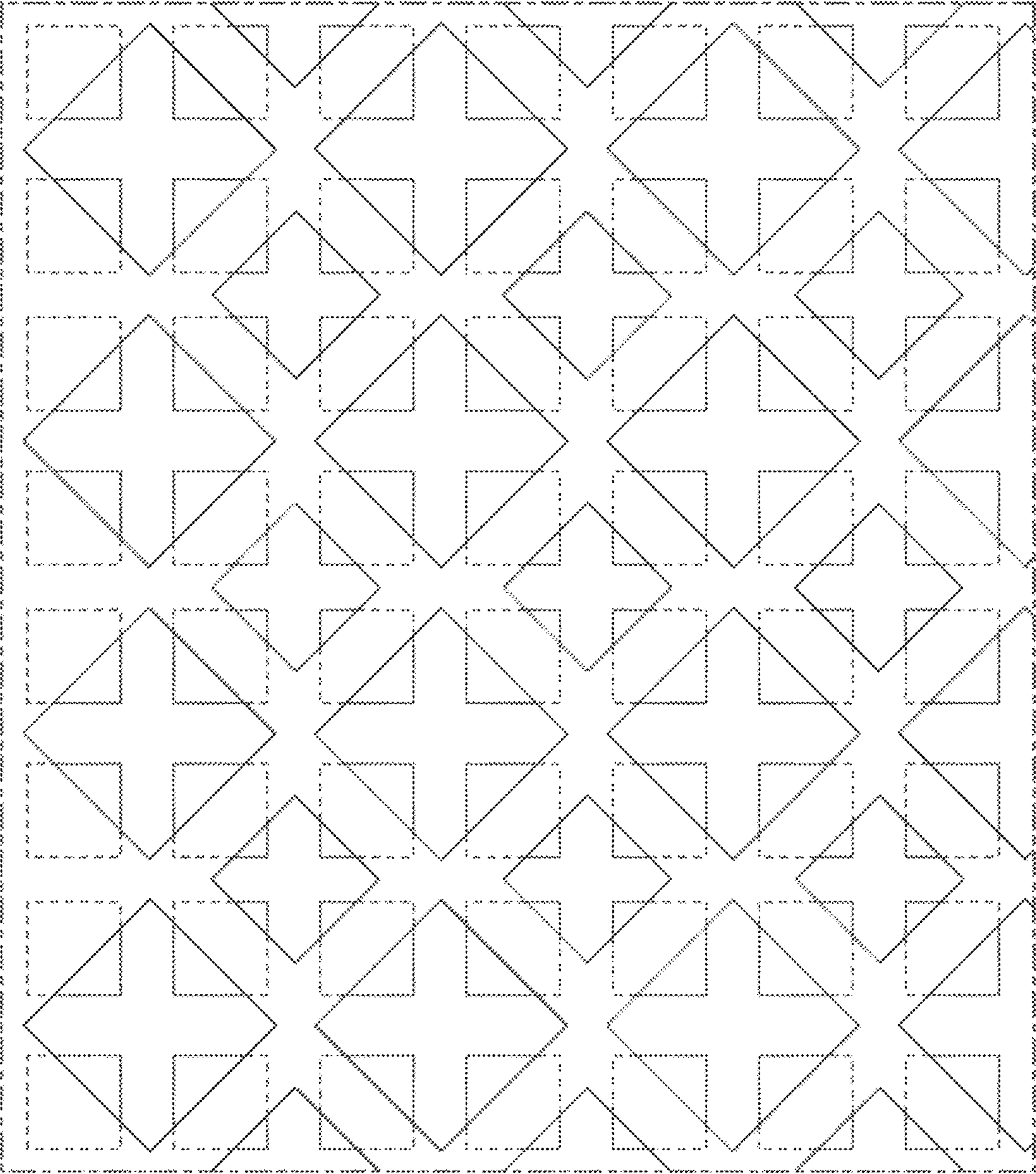


FIG. 8D

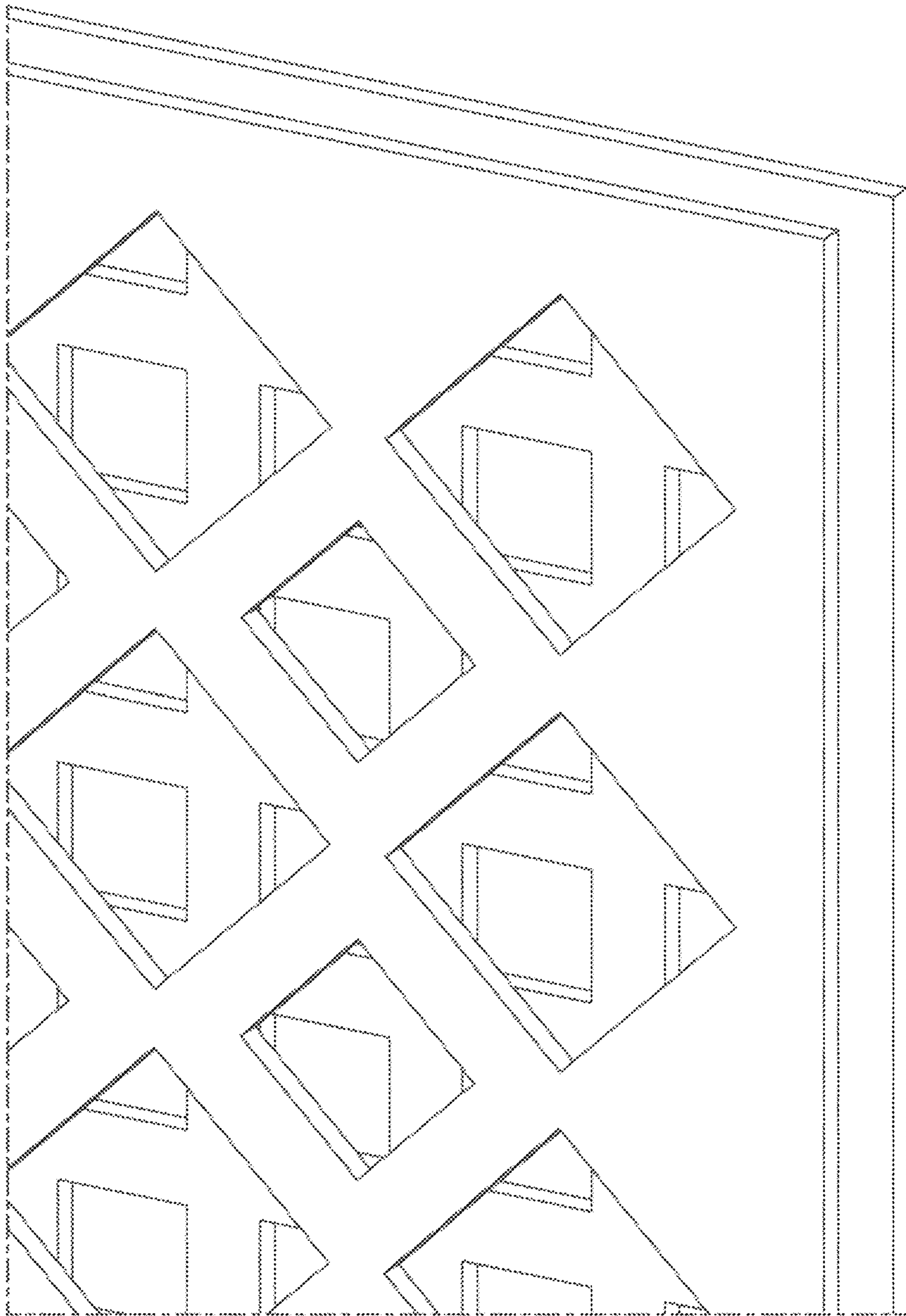


FIG. 8E

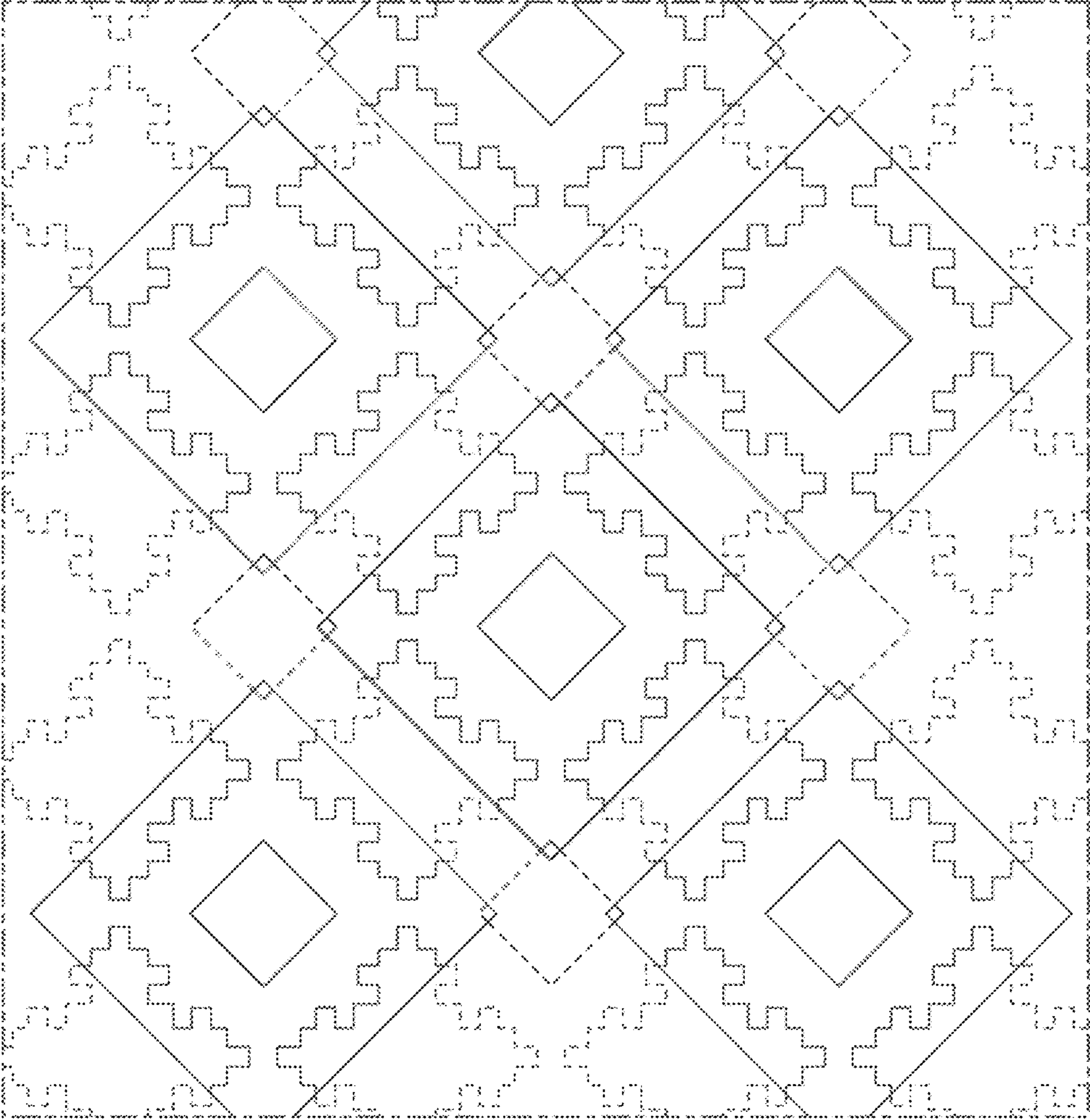


FIG. 8F

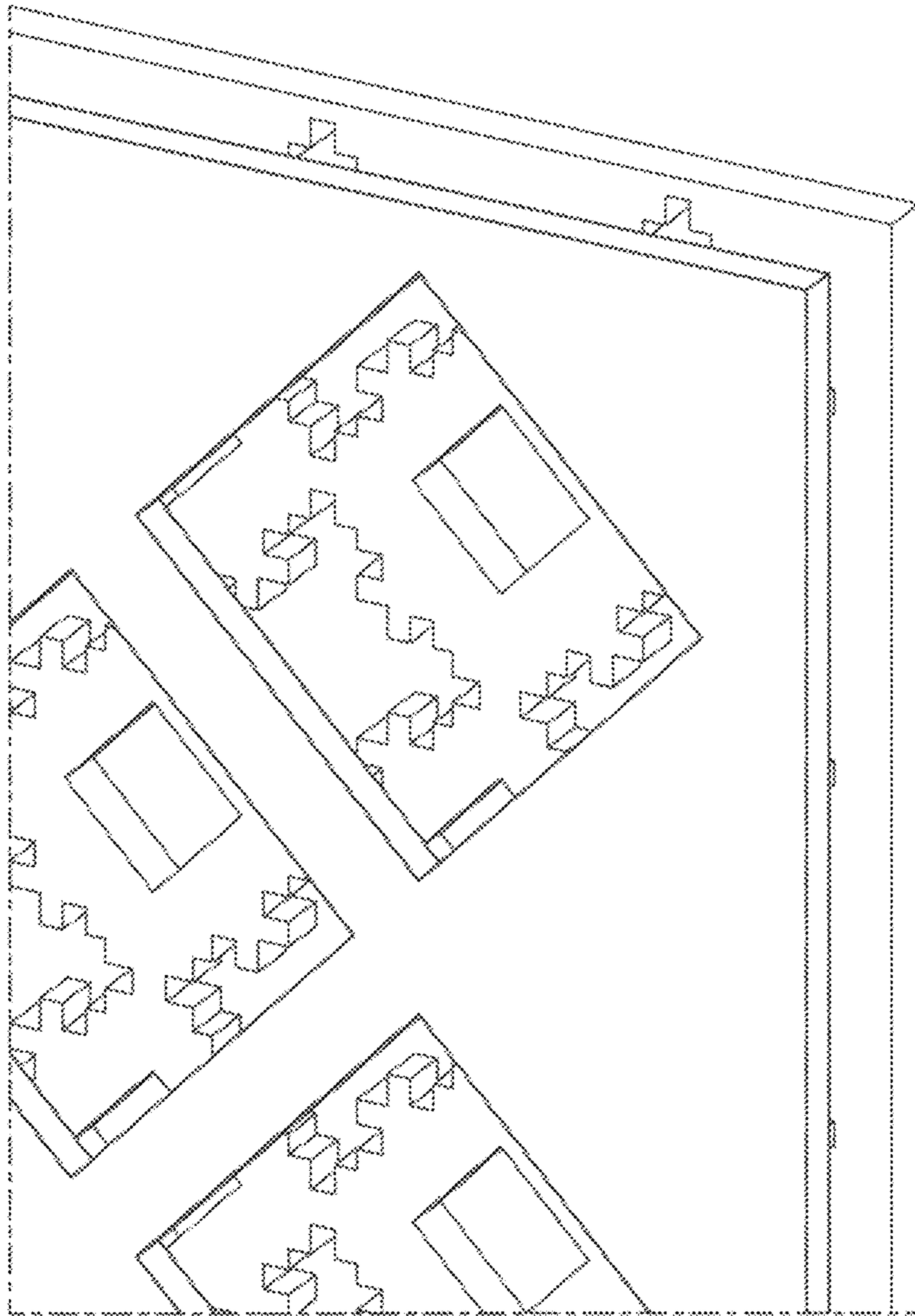


FIG. 8C

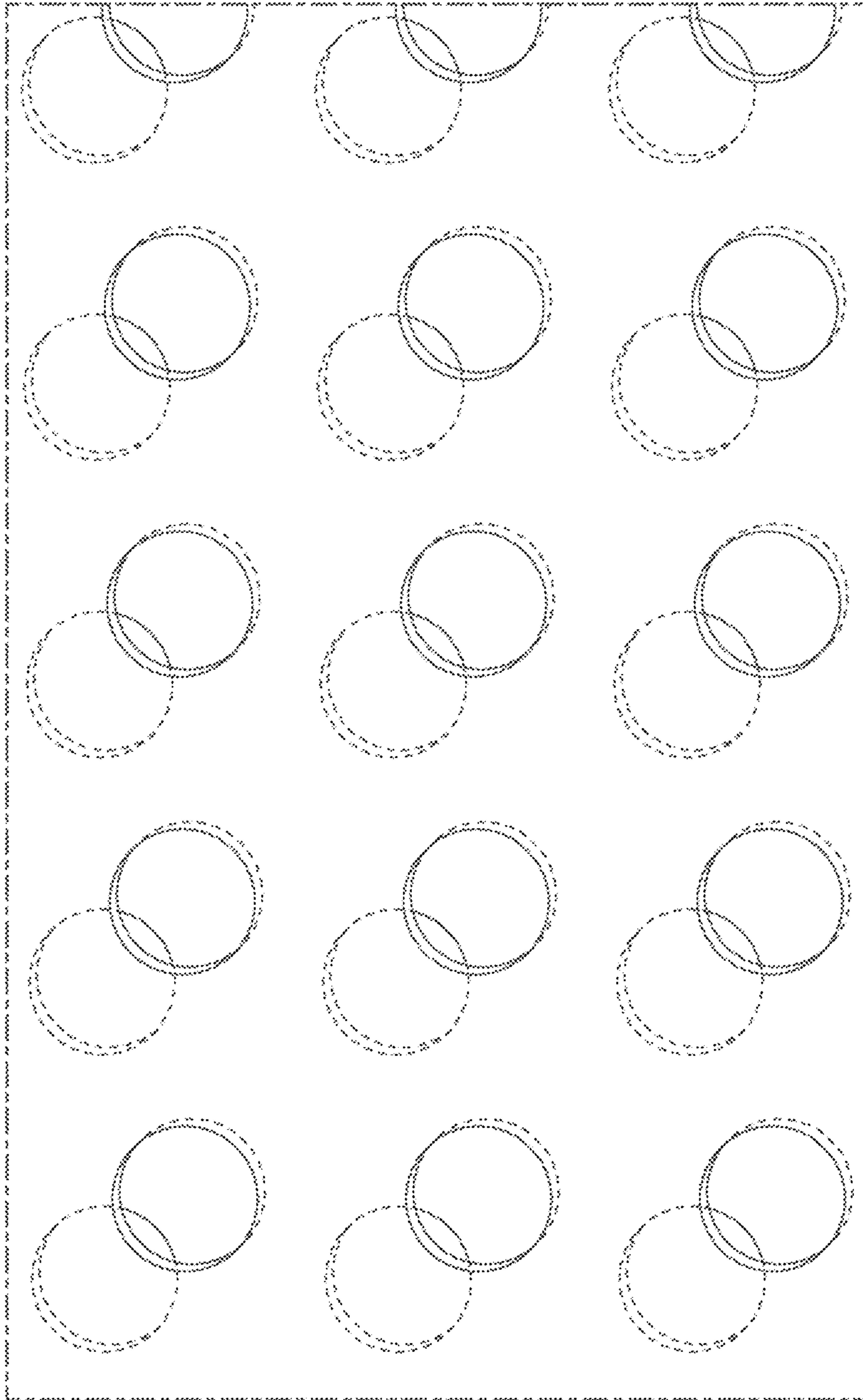


FIG. 8H

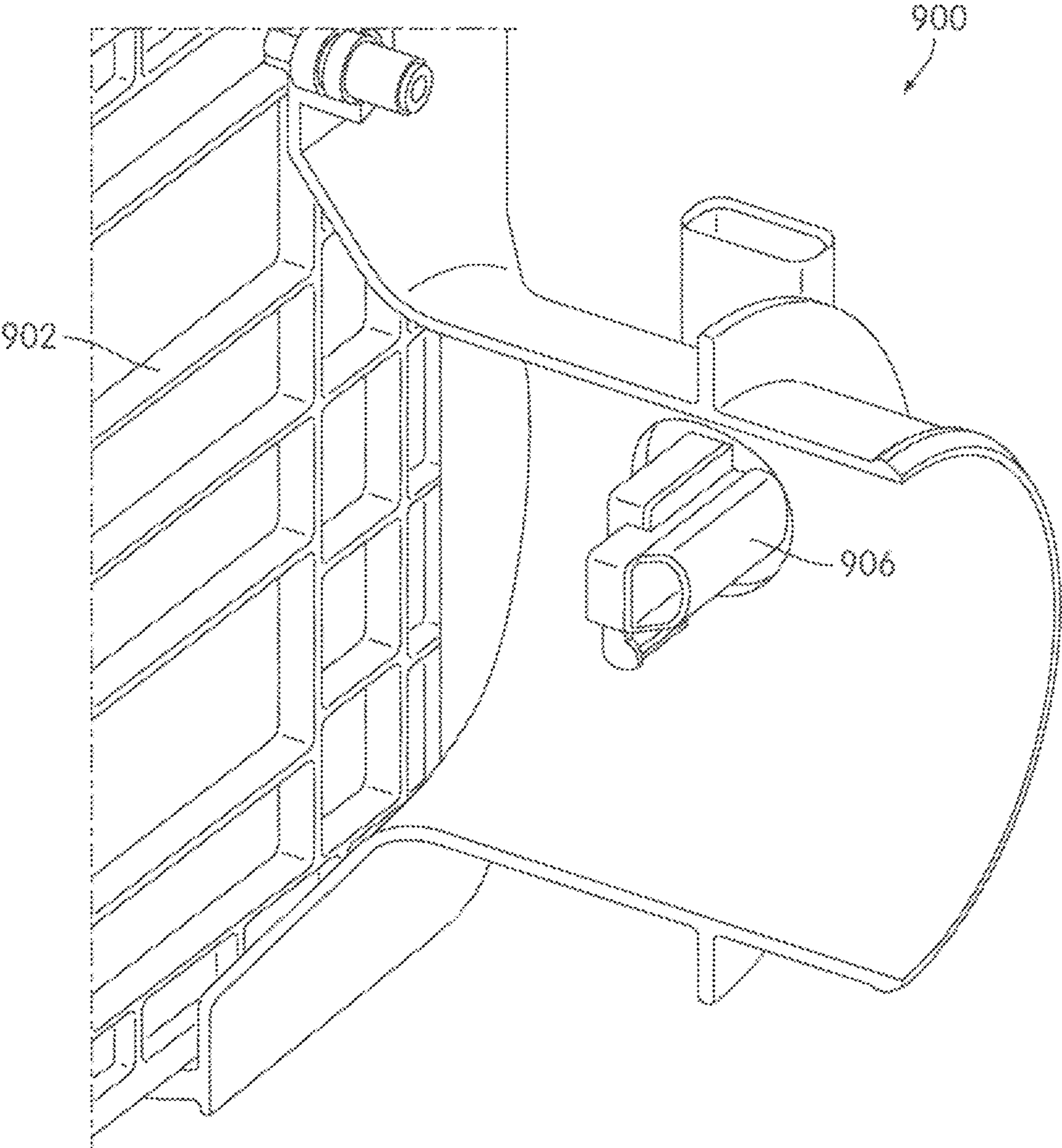


FIG. 9A

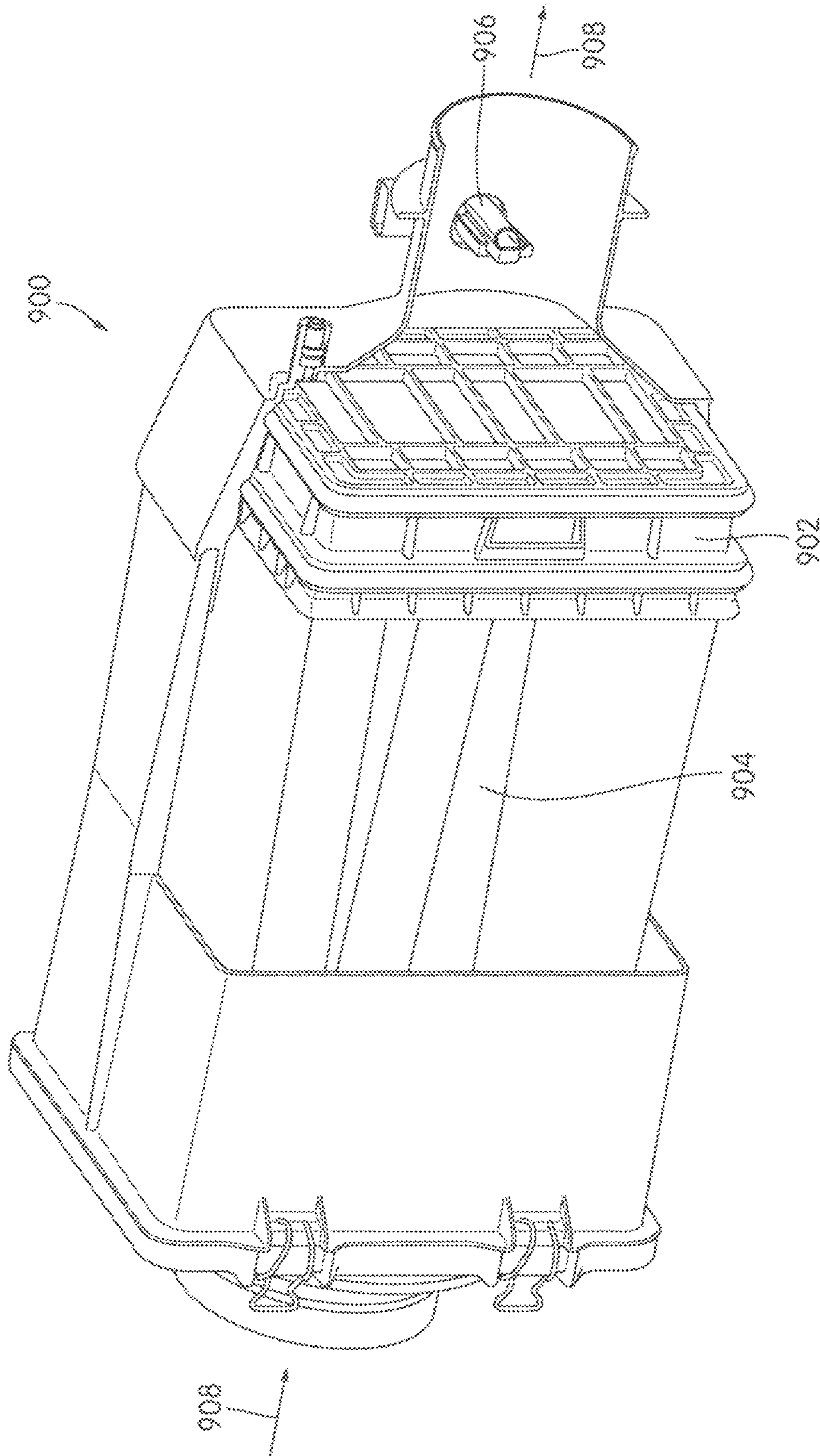


FIG. 98B

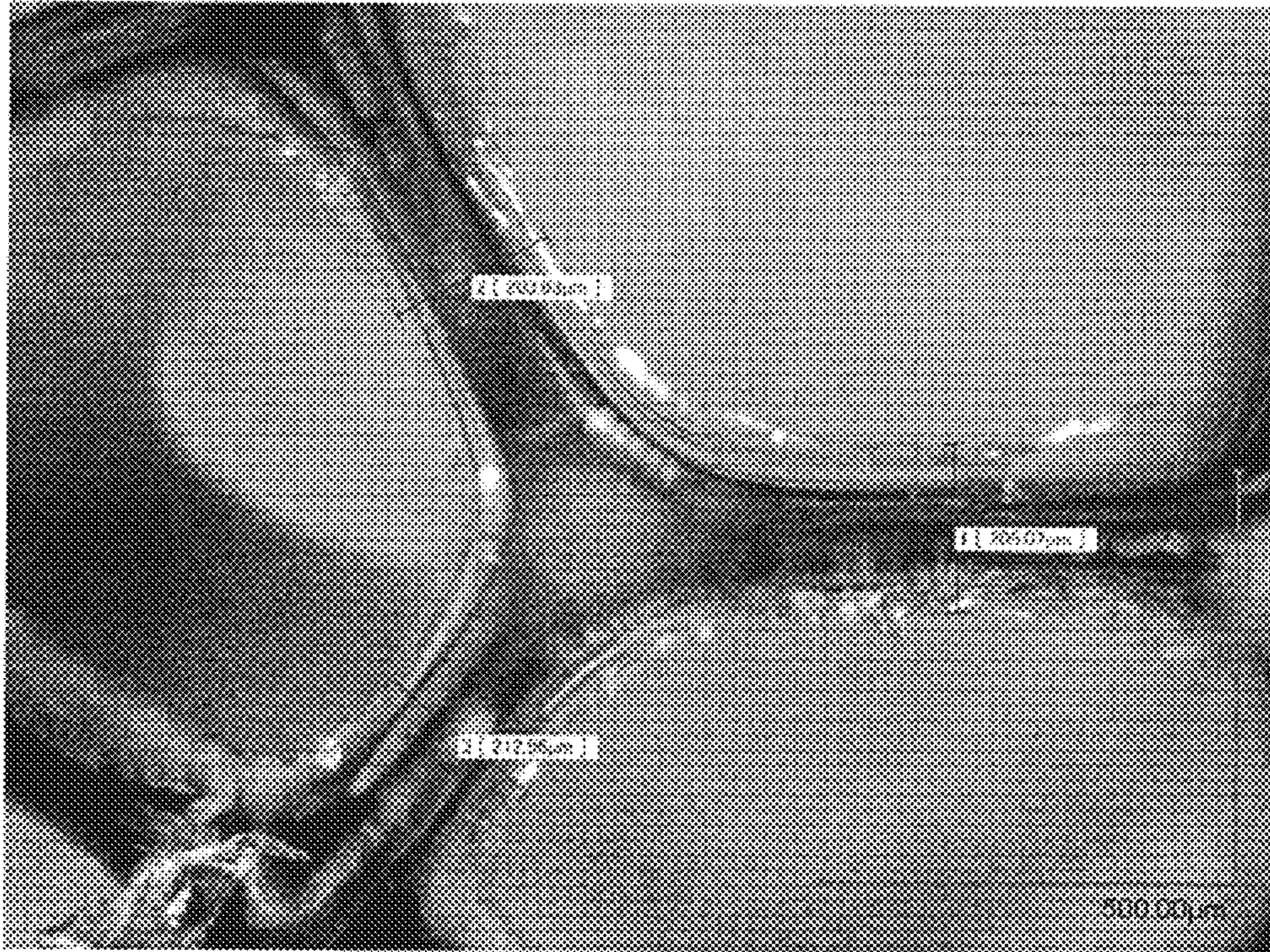


FIG. 10

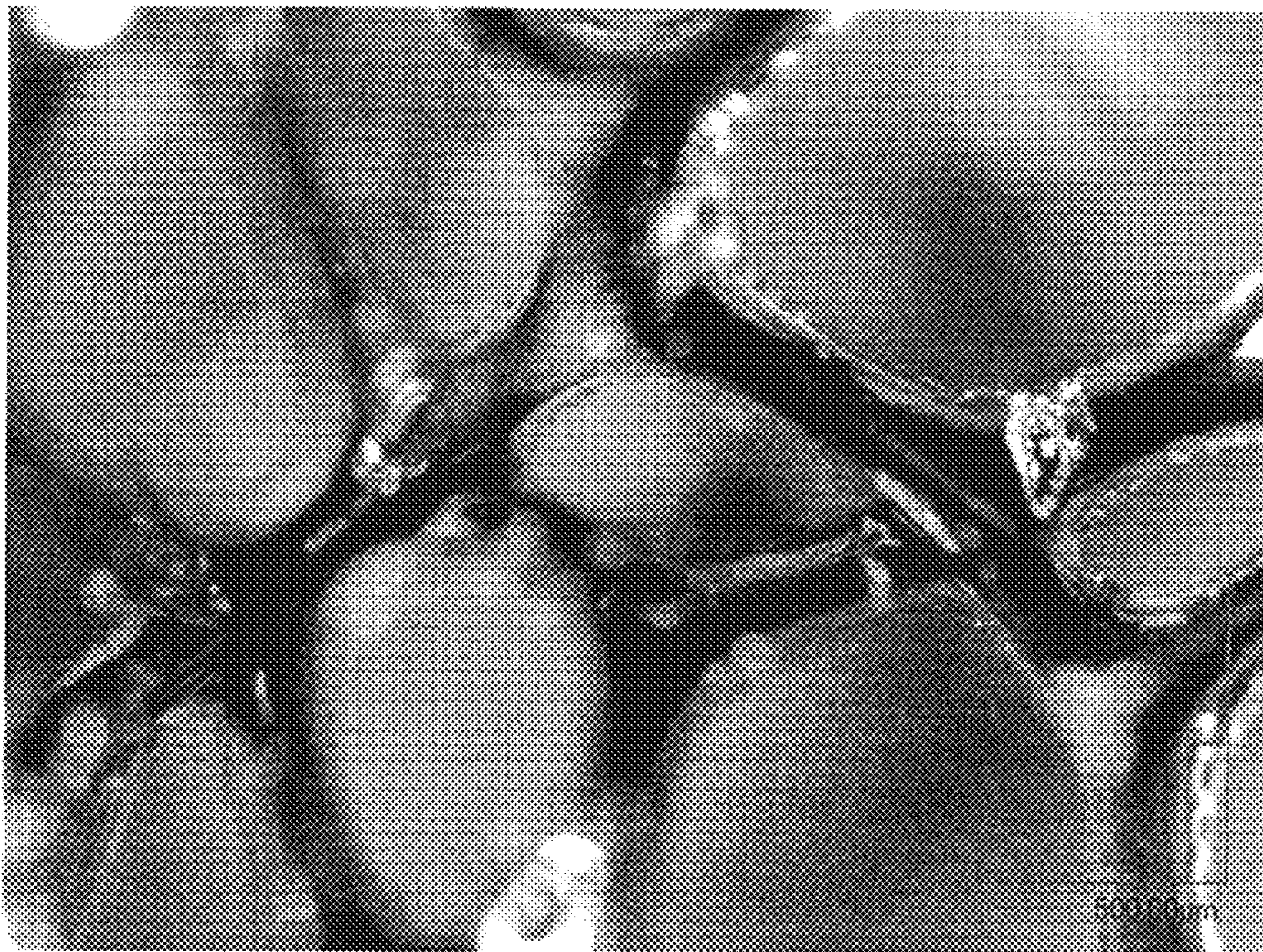


FIG. 11

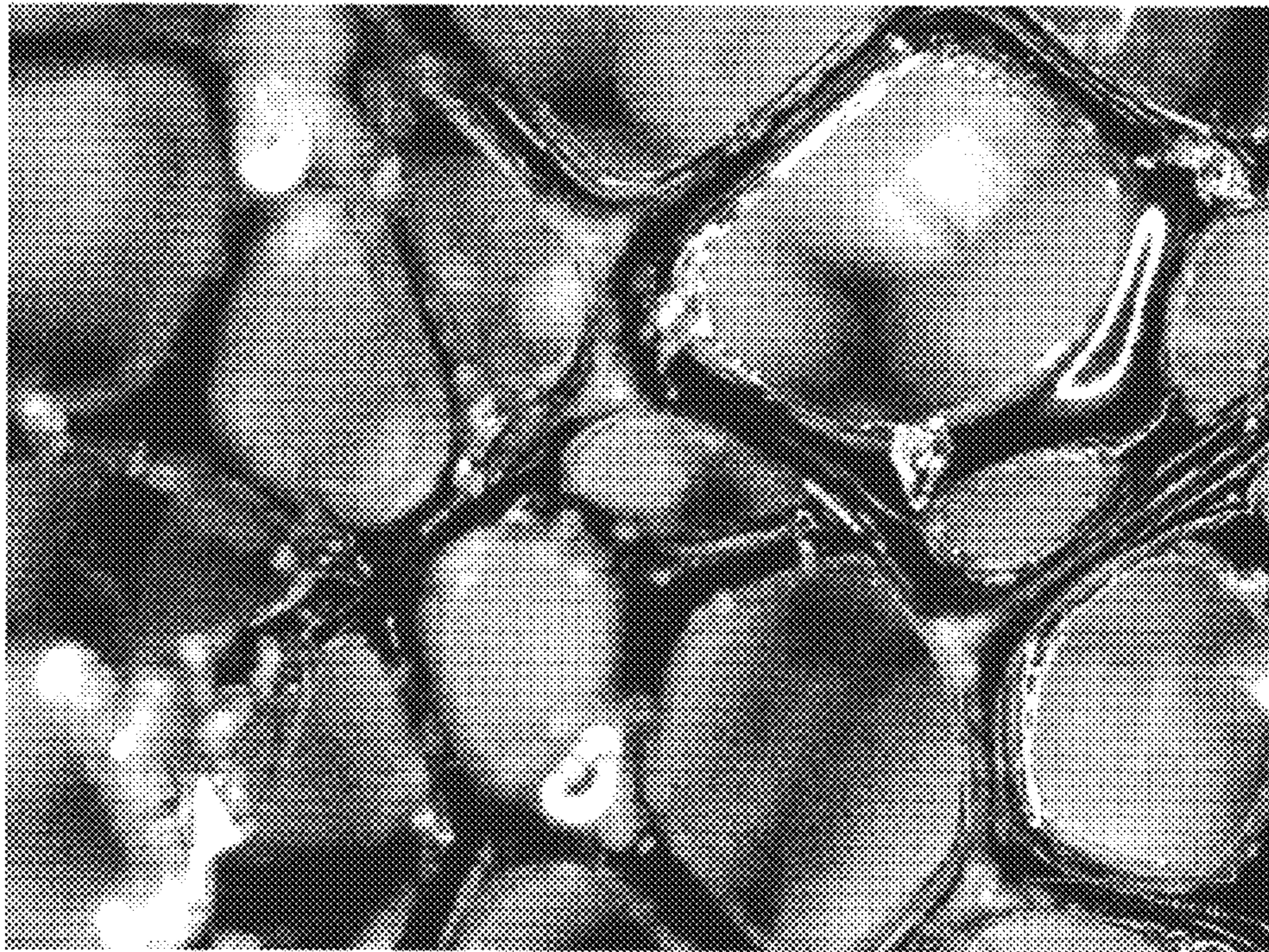


FIG 12

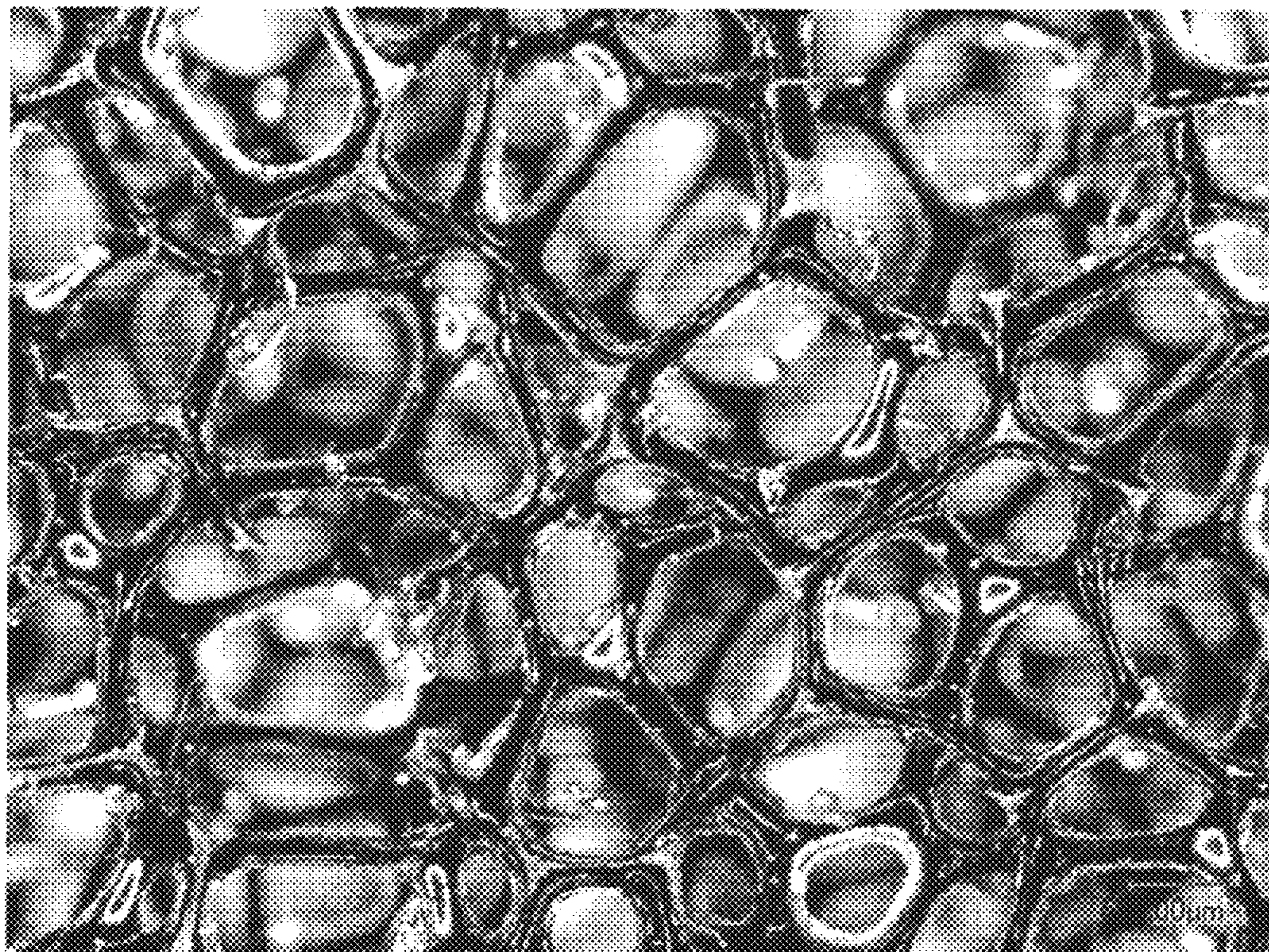


FIG. 13

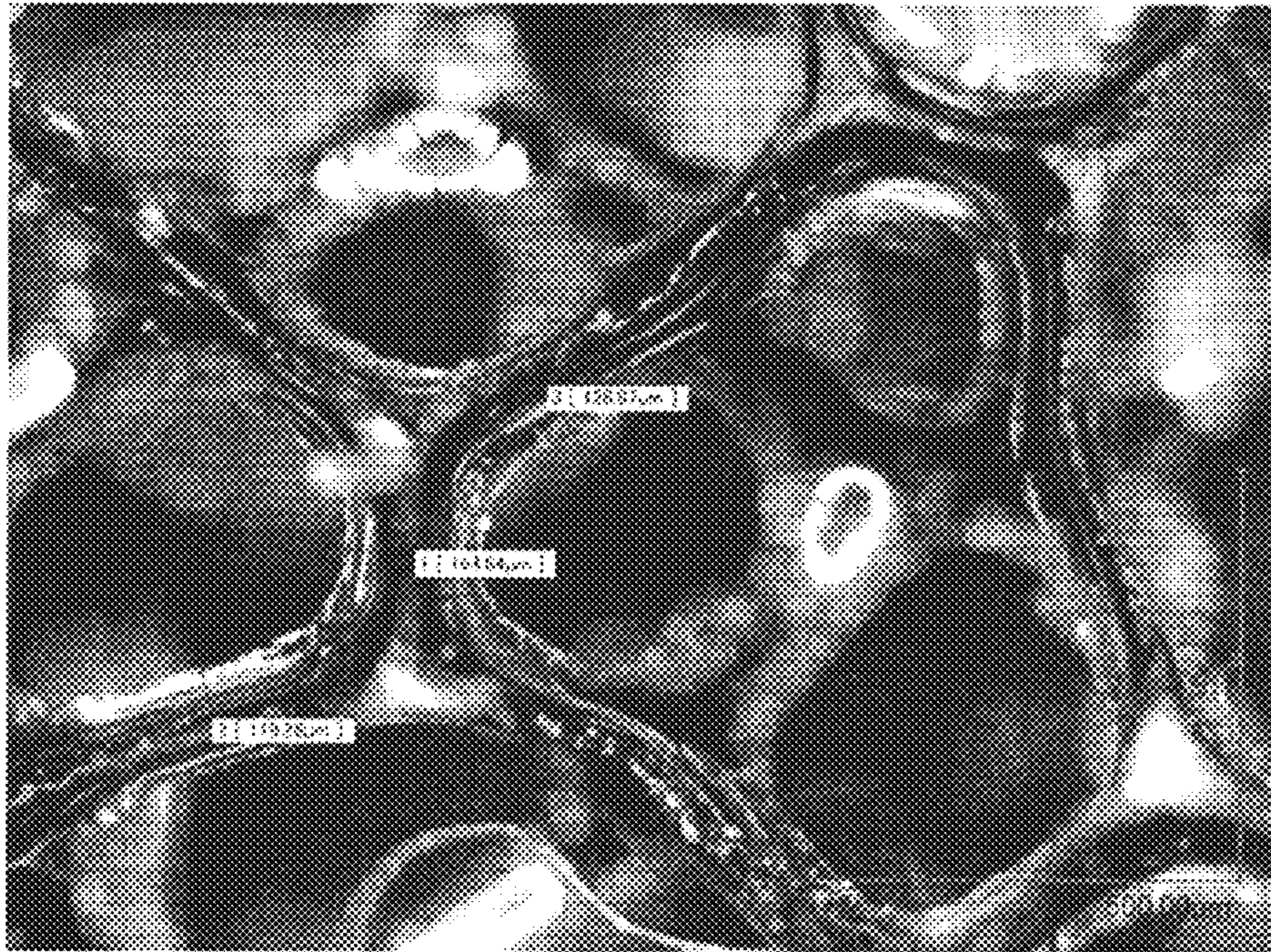


FIG. 14

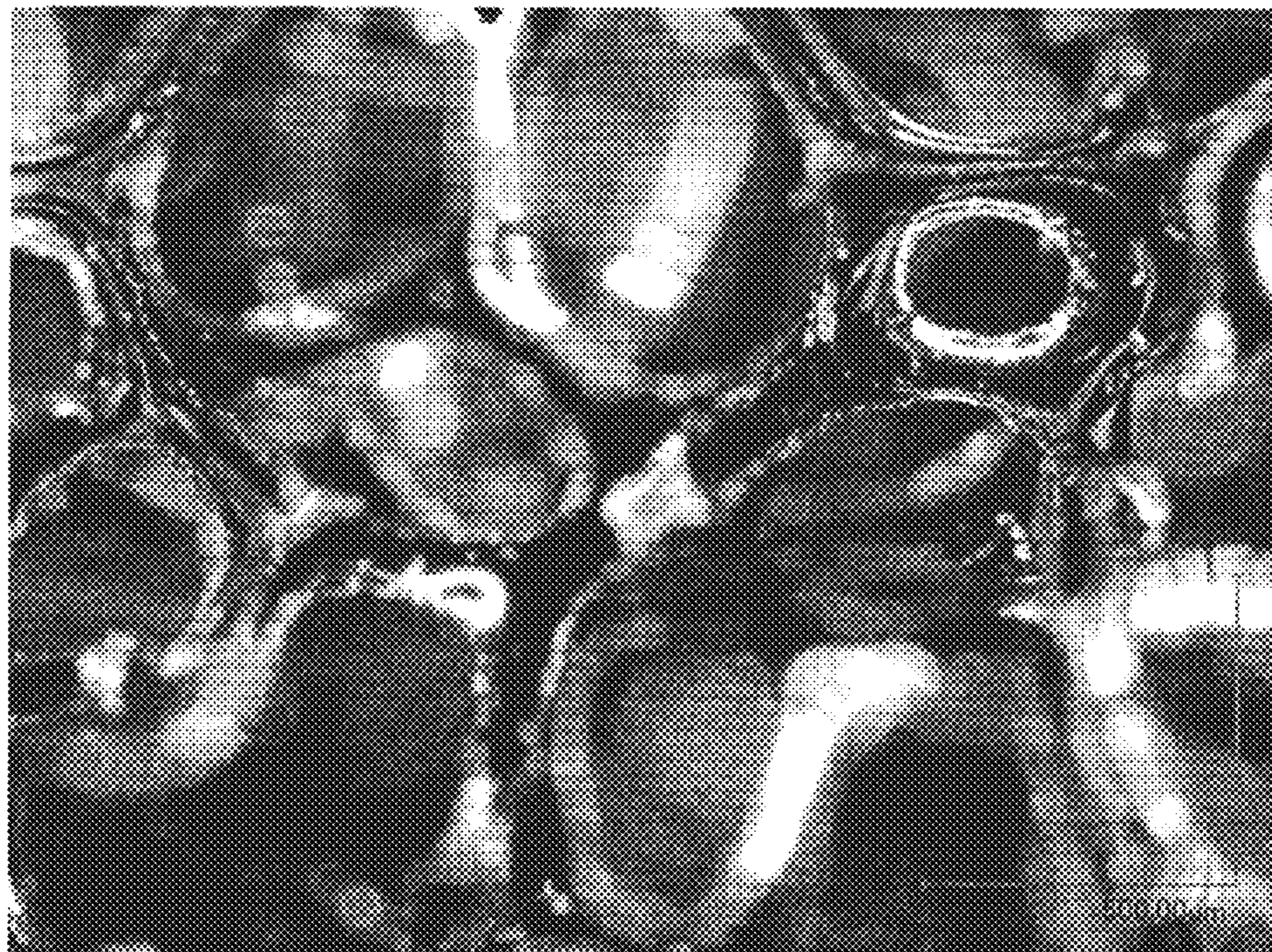


FIG. 15

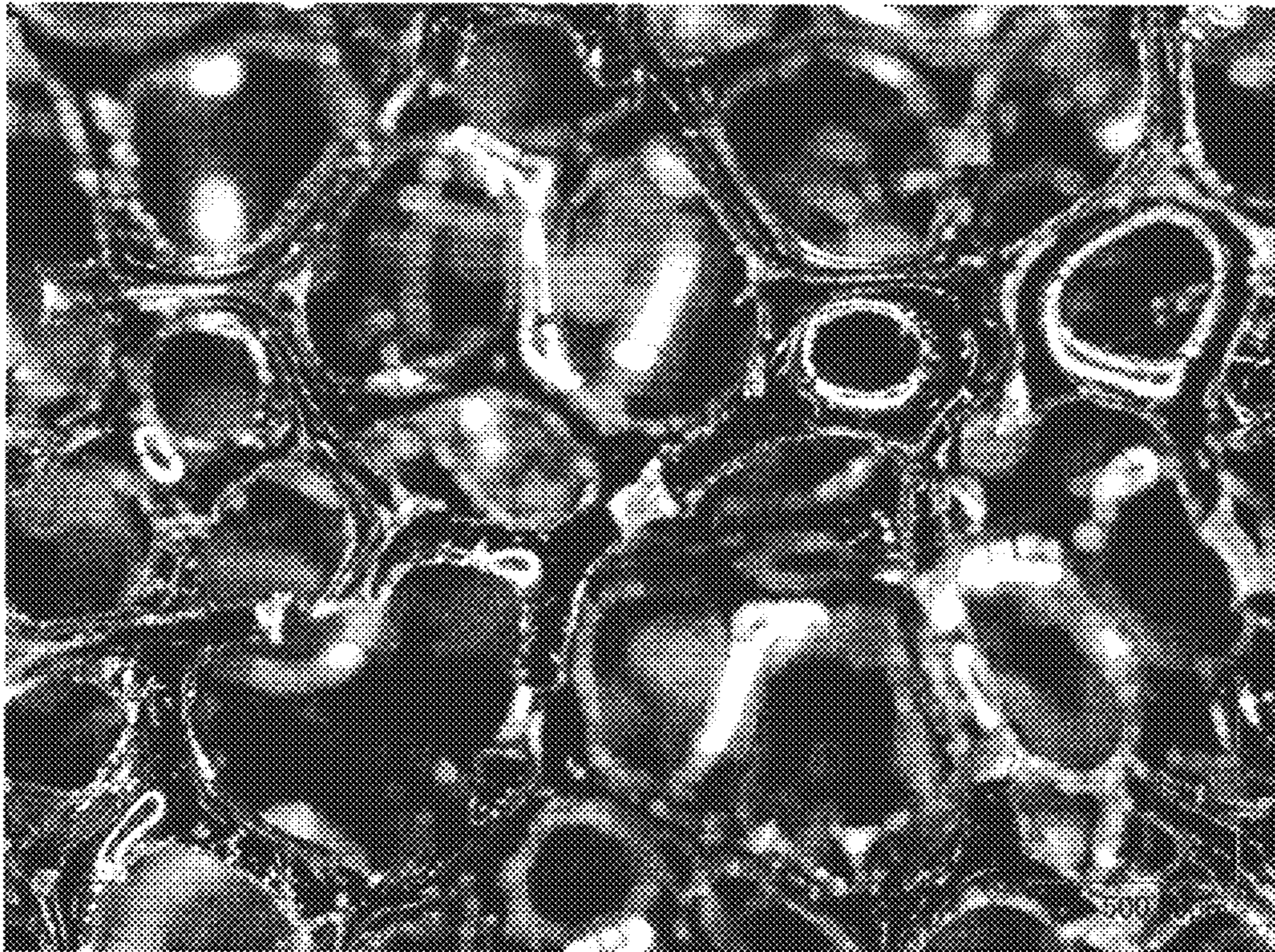


FIG. 16

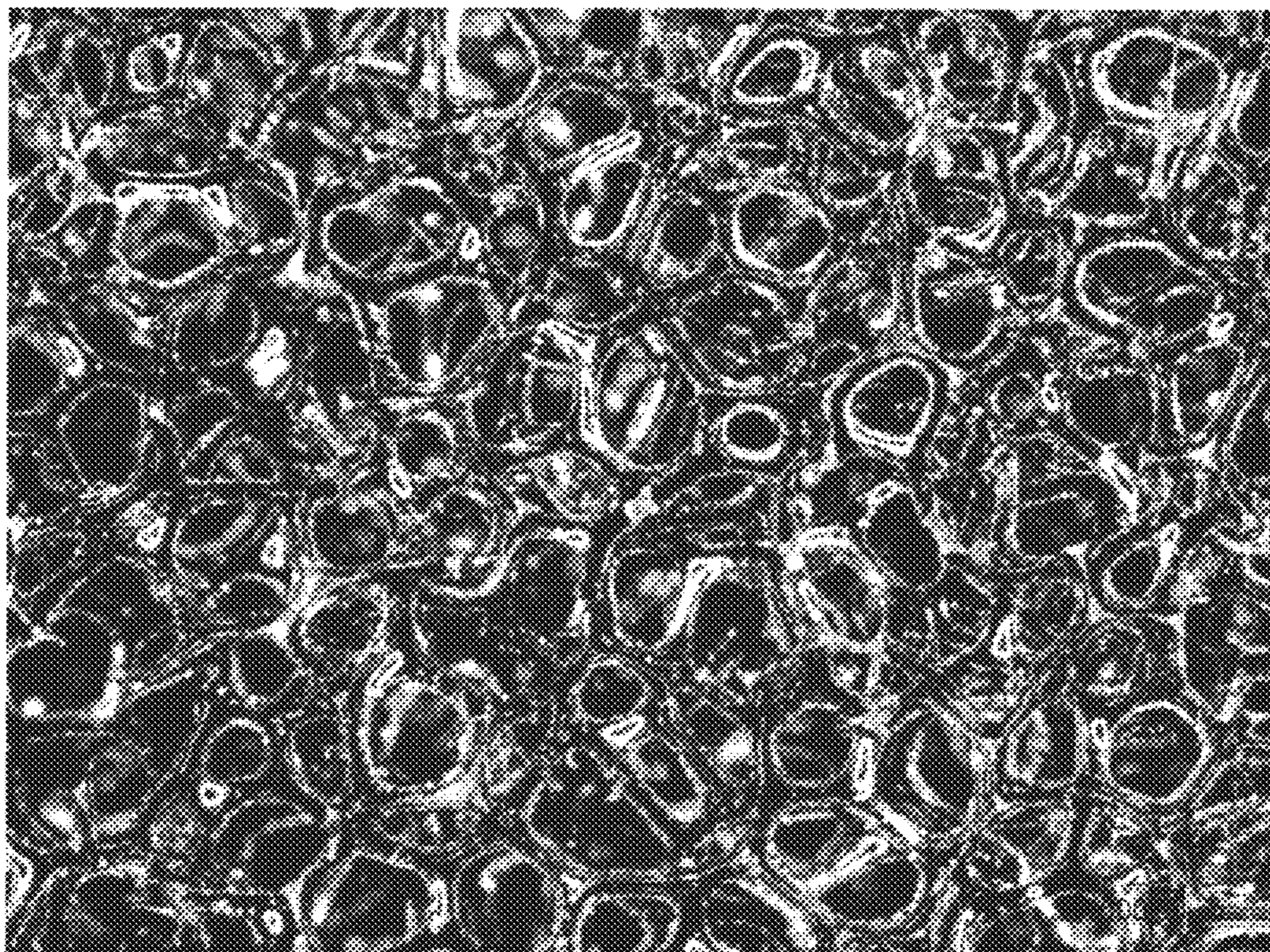


FIG. 17

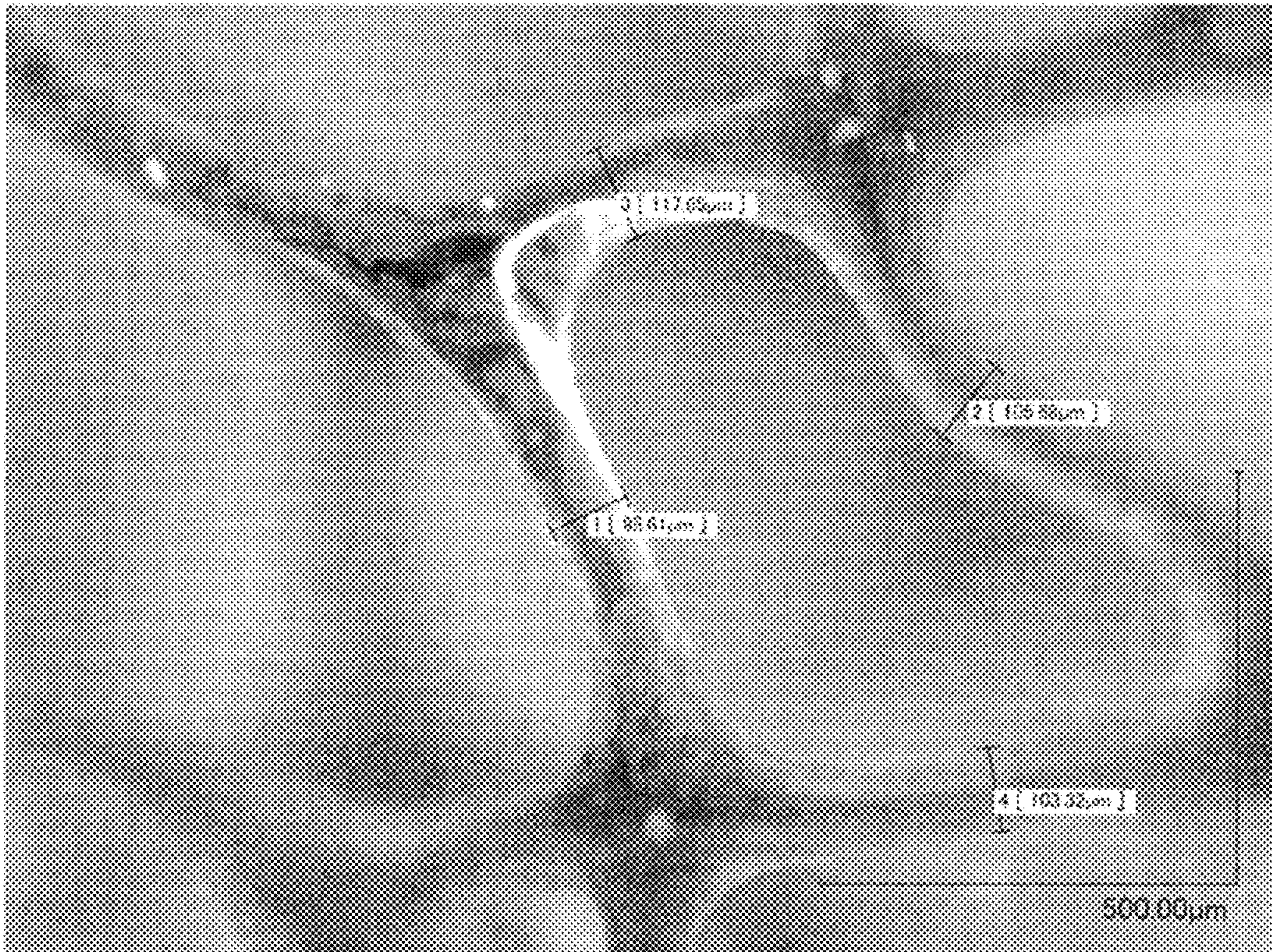


FIG. 18

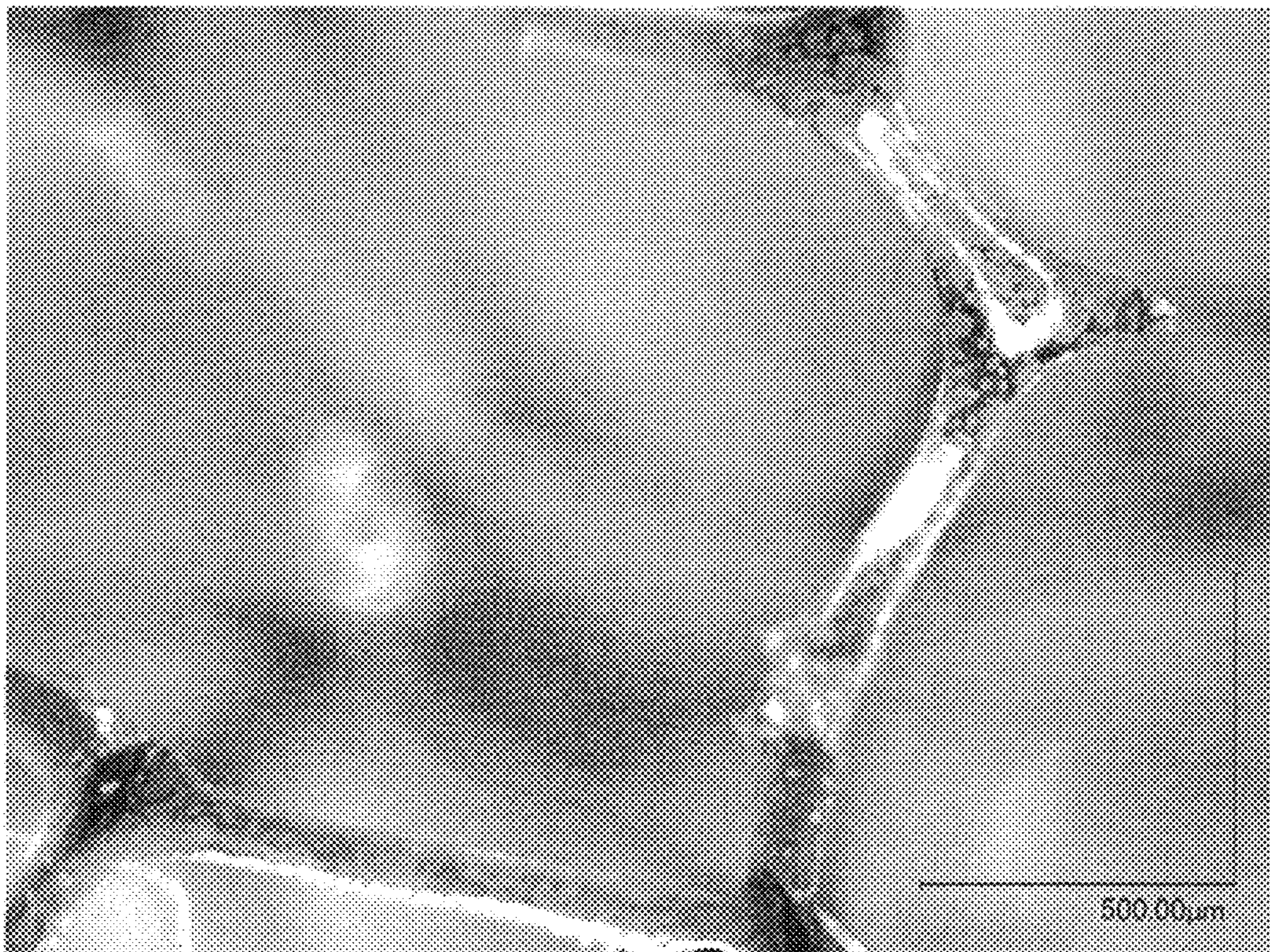


FIG. 19

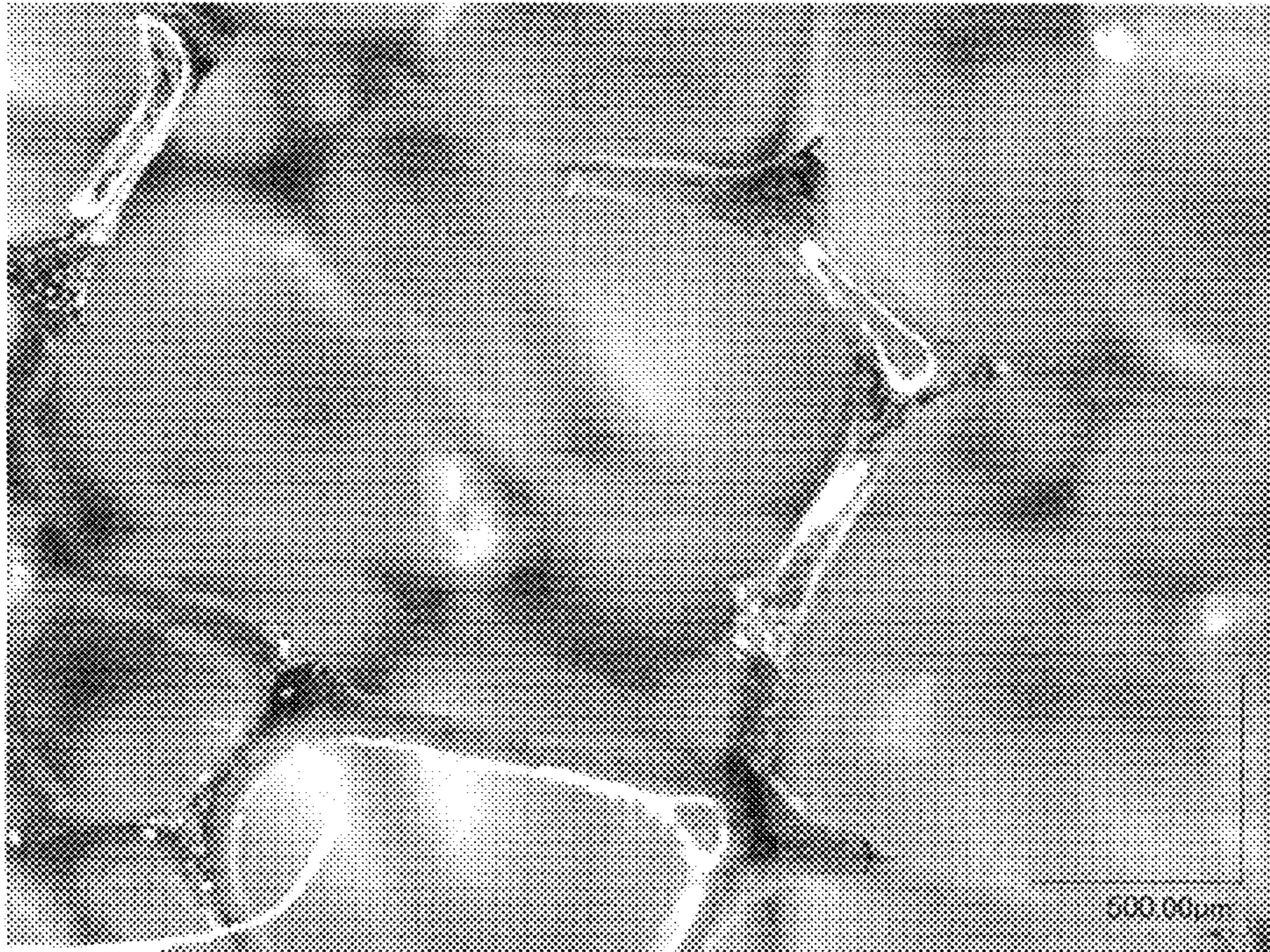


FIG. 20

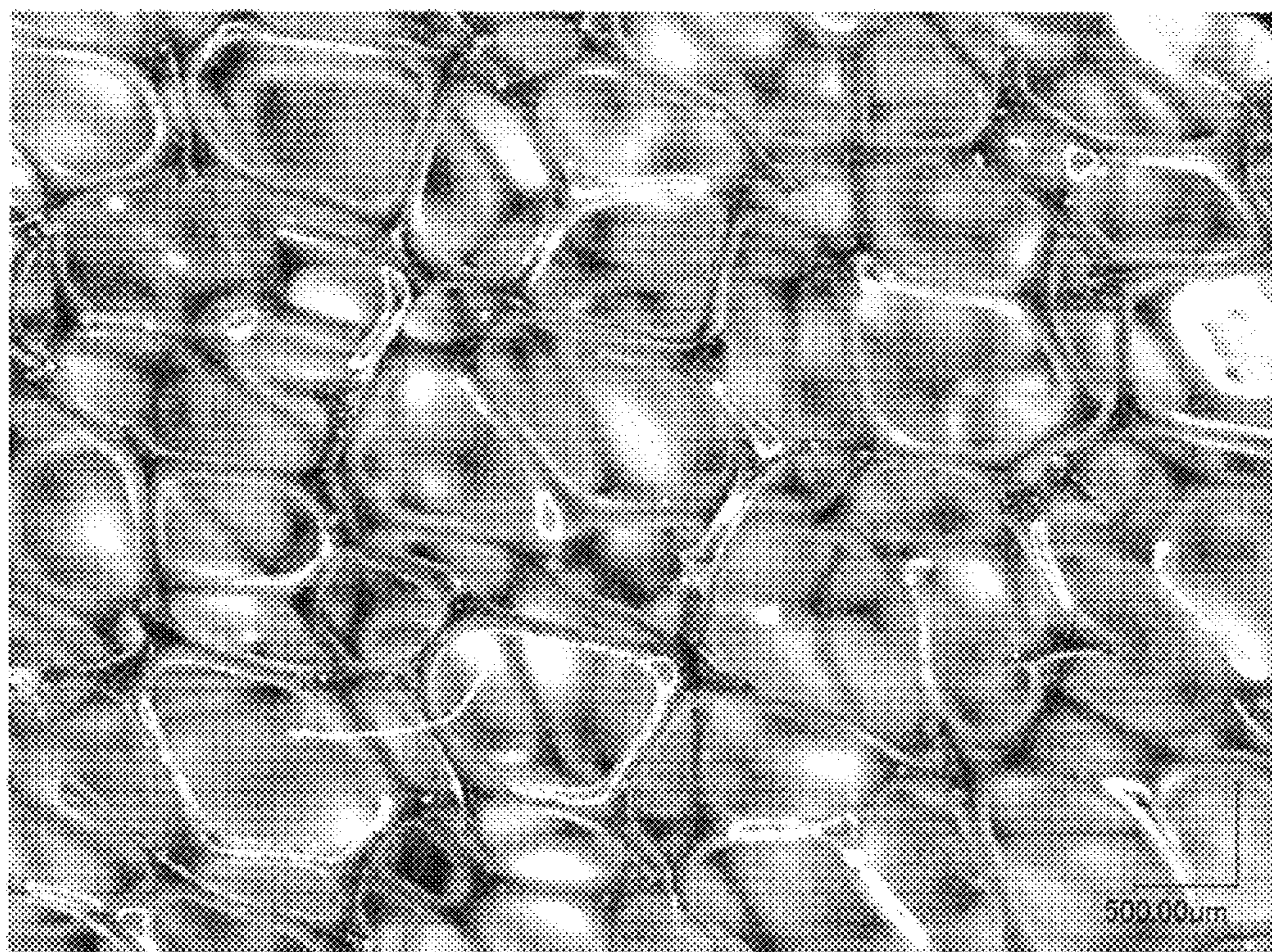


FIG. 21

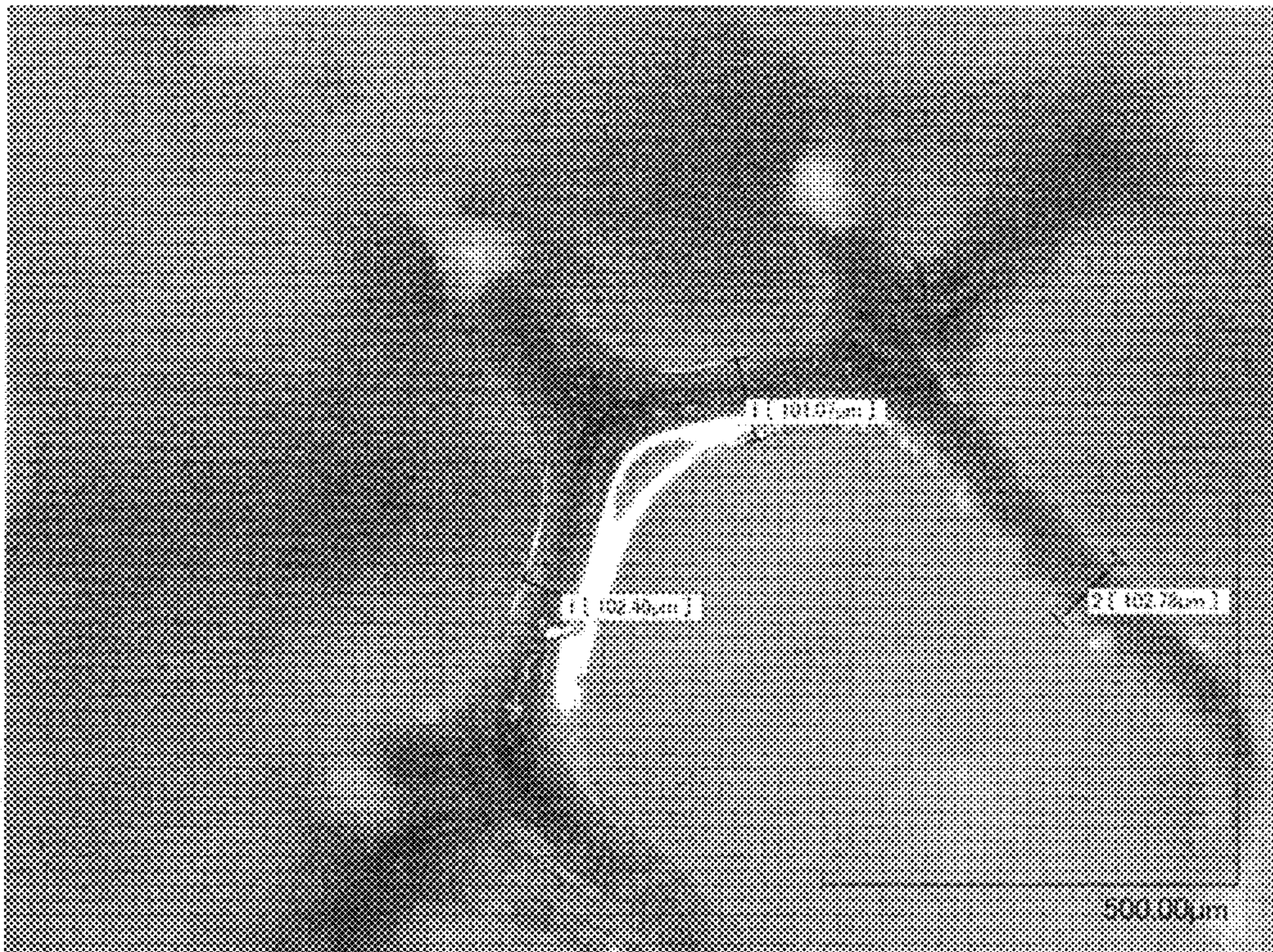


FIG. 22

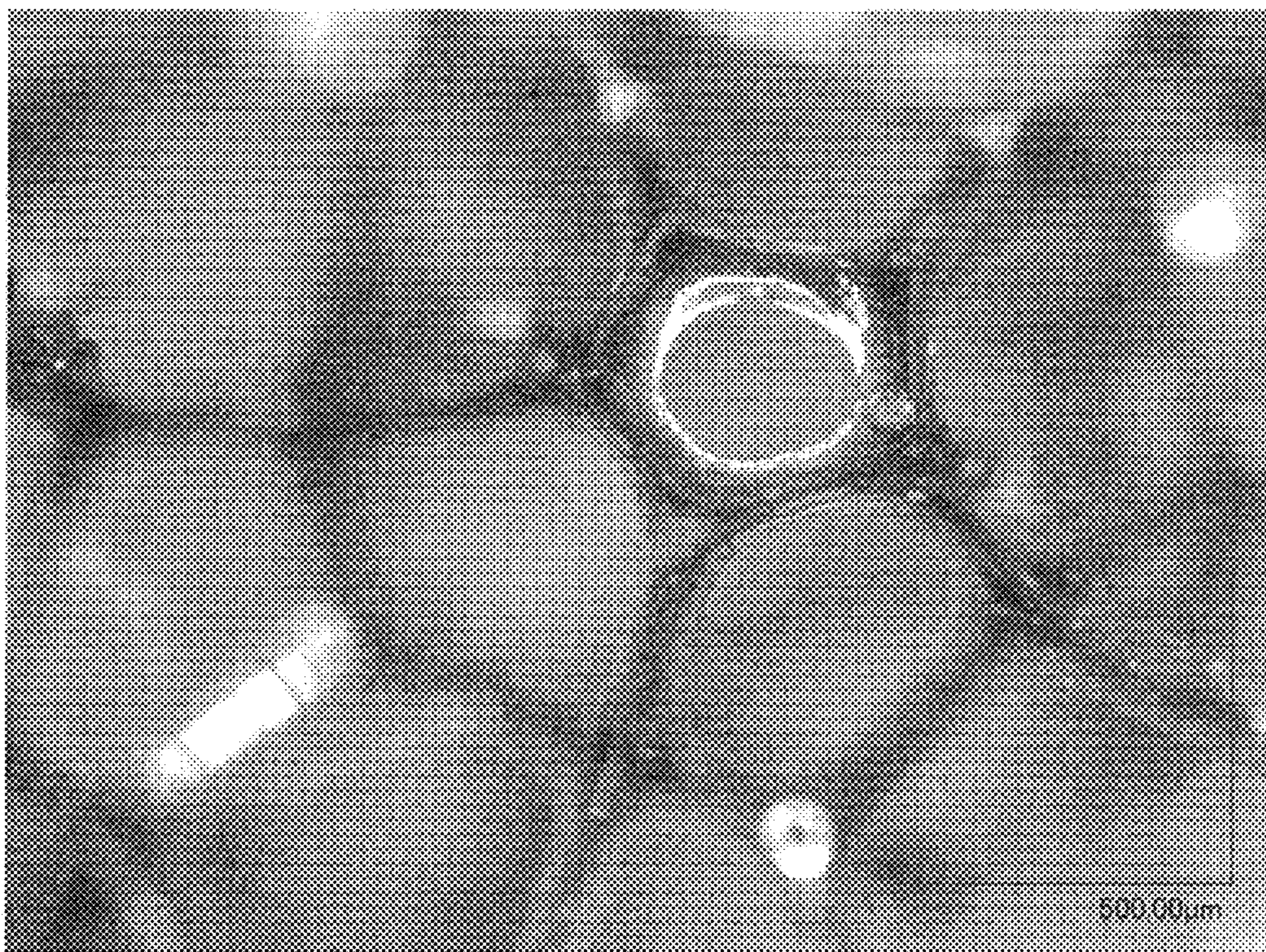


FIG. 23

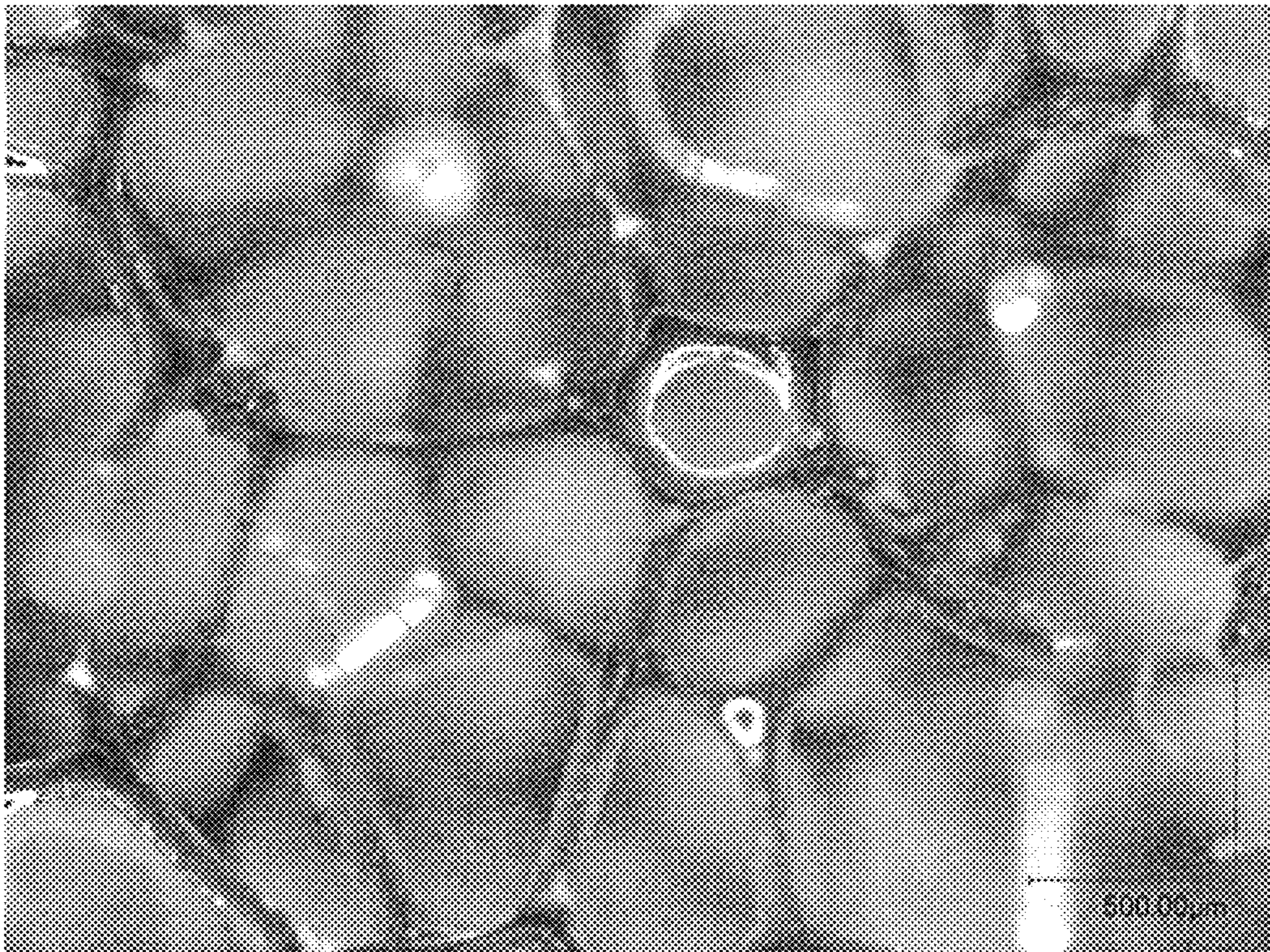


FIG. 24

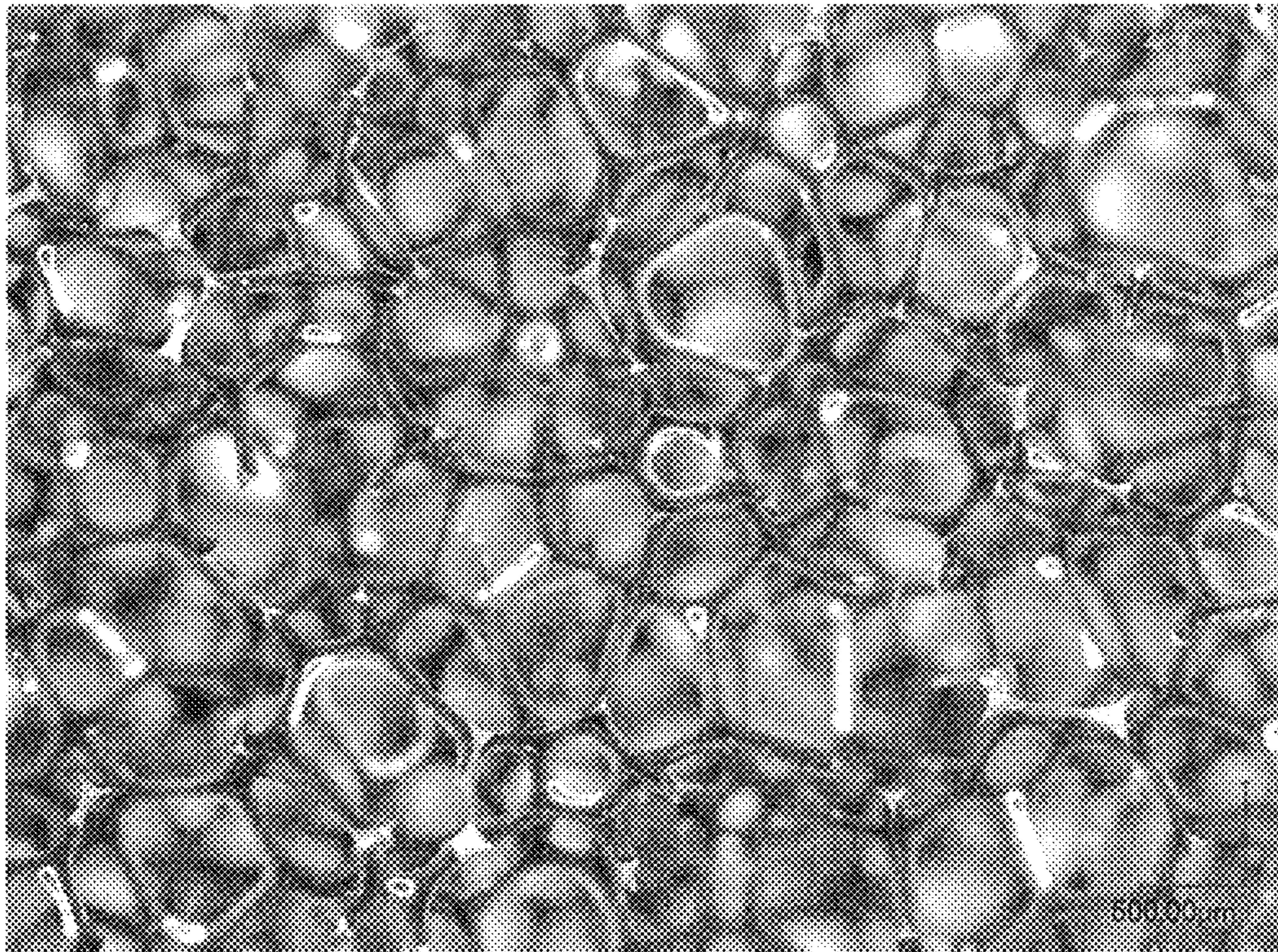


FIG. 25

SYSTEM AND METHOD FOR IMPROVING MASS AIR FLOW SIGNAL QUALITY

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 15/304,322, filed Oct. 14, 2016, which is the U.S. National Stage of PCT Application No. PCT/US2015/025582, filed Apr. 13, 2015, which claims priority to U.S. Provisional Patent Application No. 61/980,997, entitled "SYSTEM AND METHOD FOR IMPROVING MASS AIR FLOW SIGNAL QUALITY," filed on Apr. 17, 2014, the entire disclosures of which are herein incorporated by reference in its entirety.

TECHNICAL FIELD

The present invention relates generally to air filtration systems having air flow conditioning devices that improve the quality of signal from a mass air flow (MAF) sensor.

BACKGROUND

Internal combustion engines generally combust a mixture of fuel (e.g., gasoline, diesel, natural gas, etc.) and air. Prior to entering the engine, the air is typically passed through an air filtration system. A mass air flow (MAF) sensor is placed downstream of the air filter (i.e., on the clean side of the air filter media) and provides feedback to an engine control module (ECM). However, the quality of air flow exiting the filter element may be inconsistent resulting in high variation of the signal response of MAF sensor. The inconsistencies in the air flow may be the result of random stream-wise orientations of filter media pleats that result in air flow pointing directly at a MAF sensor window or results in air flow pointing away from a MAF sensor window. The inconsistencies in air flow may be the result of variation of embossment positions on the filter media pleats too. Embossments on media pleats act as spacers between the individual media pleats. Embossments also block air flow coming out from between pleats. Thus, the presence of embossments creates a flow-around-bluff-body situation, where flow structures, such as vortices, eddies, bubbles etc. can be resulted and thus affect MAF sensor signal quality. Moreover, embossments aren't precisely and repetitively positioned on media pleats relative to filter frame (i.e., some of the embossments may be closer to one edge of frame and while some embossments may be further away from other edges of the frame). The variations in embossments consequently introduce variation of flow pattern downstream of the filter media where the MAF sensor is located. The inconsistencies in air flow may also arise from other factors, such as variations of pleat shape or spacing and differing pleat counts. The present application addresses these inconsistencies and therefore improves the signal quality of MAF sensor output.

SUMMARY

One embodiment relates to a filter assembly. The filter assembly includes a support frame. The filter assembly further includes a filter media coupled to the support frame, the filter media having a dirty side configured to receive a stream of air and a clean side configured to output a stream of air that has been filtered through the filter media. The filter assembly includes a conditioning device coupled to the

support frame, the conditioning device positioned in a downstream direction from the clean side of the filter media with respect to the stream of air, the conditioning device offset from the clean side of the filter media by a separation distance. The conditioning device is a secondary device is placed upstream of a MAF sensor in an air flow duct. In particular embodiments, the conditioning device comprises a mesh screen. In other embodiments, the rectification device comprises a secondary media.

Another embodiment relates to a method of filtering a stream of air. The method includes providing a filter assembly. The filter assembly includes a support frame, a filter media coupled to the support frame, and a conditioning device coupled to the support frame and positioned in a downstream direction from a clean side of the filter media with respect to the stream of air. The conditioning device is offset from the clean side of the filter media by a separation distance. The method further includes providing a mass air flow sensor positioned downstream of the conditioning device with respect to the stream of air. The method includes routing the stream of air through the filter media, and then routing the stream of air through the conditioning device. The method still further includes routing at least a portion of the stream of air past the mass air flow sensor.

These and other features, together with the organization and manner of operation thereof, will become apparent from the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 shows an exploded perspective view of a filter panel housing according to an exemplary embodiment.

FIG. 2 shows a front view of an air conditioning mesh having a varying pore pattern according to an exemplary embodiment.

FIG. 3 shows an exploded perspective view of a filter assembly according to an exemplary embodiment.

FIG. 4 shows an exploded perspective view of a filter assembly according to an exemplary embodiment.

FIG. 5 shows a perspective view of an arrangement of a foam media and a pleated media of the filter assembly of FIG. 4.

FIGS. 6-7 show various testing data associated with air flow conditioning devices.

FIGS. 8A through 8H show views of exemplary 2D and 3D fractal arrangements that may be utilized as the second air flow conditioning device.

FIGS. 9A and 9B show a schematic of an air filtration system, where a secondary filter and a flow conditioning device are located.

FIGS. 10-13 show close up perspective views of a 30 pores per inch (PPI) foam media according to an exemplary embodiment.

FIGS. 14-17 show close up perspective views of a 45 PPI foam media according to an exemplary embodiment.

FIGS. 18-21 show close up perspective views of a 30 PPI foam media according to another exemplary embodiment.

FIGS. 22-25 show close up perspective views of a 45 PPI foam media according to another exemplary embodiment.

DETAILED DESCRIPTION

Referring to the figures generally, the various embodiments disclosed herein relate to air flow conditioning devices that improve the quality of mass air flow (MAF) sensor signal output in air filtration systems. The condition-

ing devices improve the accuracy and consistency of MAF sensor output by reducing or eliminating the above-described inconsistencies in air flow downstream of filter media. The MAF sensor may provide an output to an engine control module (ECM) of an internal combustion engine that receives filtered air from the air filtration system. The conditioning device is a secondary device placed downstream of an air filter media and upstream of a MAF sensor in an air flow duct of the filtration system. The conditioning device reduces defects in the air stream exiting the filter media. The conditioning devices may be a mesh screen, a wire mesh, a foam, a perforated plate, or the like. Such conditioning devices provide an improved MAF sensor signal output in terms of normalized variation, which is defined below by equation 1.

$$\text{Normalized variation} = \frac{dQ}{Q} \% \quad (1)$$

In equation 1, Q is the bench mark flow rate at which the MAF-integrated system is tested, dQ is the maximum deviation of flow rates reported by MAF sensors of a group of MAF-integrated application from bench mark flow rate Q. Better MAF signal performance involves the removal or mitigation of part-to-part variation of the group of MAF-integrated application, by means of a flow conditioning device which is the purpose of current disclosure.

Additionally, since the conditioning devices are intended to be physically added to existing to filter panel frame by either over-mold or other means of manufacturing and is based on existing structure, potential changes and modifications, and thus the cost of them, to existing tooling and design are minimal.

As an air stream passes through a filter media, the air stream is disrupted. The degree of flow disruption is highly dependent on geometry of filter media pleats. This disruption translates any part-to-part variation of geometry of the filter media to any MAF sensors downstream of the filter media, which results in inconsistent and/or inaccurate outputs from the MAF sensors to an ECM or other devices. Adding a flow conditioning device with an appropriate K-factor downstream of the filter media helps to condition the air stream in order to provide a more accurate and more consistent MAF sensor signal outputs. The K-factor of a flow conditioning device is defined by equation 2 below.

$$K = \frac{\Delta p}{\frac{1}{2}\rho v^2} \quad (2)$$

In equation 2, Δp is the pressure drop caused by the flow conditioning device, ρ is the density of the air, and v is the face velocity of the air stream going through the media. If the K-factor is zero, there is no pressure drop across the flow conditioning device, such scenario corresponds to an arrangement where no flow conditioning is used. The minimum K-factor of the conditioning devices is preferably approximately 8. In some arrangements, the minimum K-factor is approximately 1-10. The maximum useful K-factor is estimated to be approximately 100 (beyond which, all allowed Δp of entire filter housing assembly is consumed by the flow conditioning device alone). The K-factor may be affected by the thickness of the conditioning device (e.g., the thickness of a layer of foam), the porosity (ratio of air

volume/solid volume within the structure of the device) of the conditioning device, the pore size of the conditioning device if the conditioning device is comprises of foam-like materials, relative opening area of the material if the material is, e.g. perforated plate etc. By a conditioning device having the appropriate factor, unexpected disturbances caused by the inconsistencies of the filter media (e.g., caused by orientation effects, deformation from water soak, etc.) are mitigated.

Separation distance between the flow conditioning device and the filter media is another critical parameter, since most of filter media is made of media pleats, which causes inconsistencies in air stream. Adequate separation distance allows the inconsistencies in air stream to be diffused to some extents before air stream enters into the flow conditioning devices. The range, of such separation distance is approximately 0.1 of a pleat tip gap to 100 times of a pleat tip gap.

Secondary Mesh Screen Arrangements

Referring to FIG. 1, an exploded perspective view of a filter panel housing **100** is shown according to an exemplary embodiment. The filter panel housing includes a frame **102** and a mesh **104**. The frame **102** may be a standard seven inch by seven inch housing. The housing **100** may be inserted into an air filtration system (e.g., as shown in FIG. 9). The air filtration system provides filtered air to a device, such as an internal combustion engine. The frame **102** includes a compartment **106** configured to secure a filter media (not shown). The mesh **104** is positioned in a downstream direction from the compartment. The filter media may be a foam-based filter media or a pleated filter media. The air filtration system in which the housing **100** is installed in may include a MAF sensor downstream of the housing **100**. The mesh **104** is positioned between the filter media and the MAF sensor. The mesh **104** is attached to the bottom plane of the housing **102**. The mesh **104** may be a plastic or metal mesh. The mesh **104** may be planar (i.e., flat) or slightly curved (e.g., concave or convex with respect to the air flow direction **108**). A slightly curved mesh **104** increases the area through which an air stream goes through thereby decreasing the face velocity and the pressure drop across the mesh **104**. The mesh **104** acts as an air flow conditioning device. Air to be filtered flows in an air flow direction **108** through the air filter media. After the air passes through the air filter media (and the compartment **106**), the air passes through the mesh **104**.

The mesh **104** is molded into the frame **102** (e.g., over-molded) at a location downstream of the compartment **106**. The mesh **104** is offset from the clean side of the filter media by a distance **110**. A support frame **112** of the housing **102** may support the mesh **104** and maintain the mesh at the distance **110** from the filter media.

The distance **110** is greater than zero. The distance **110** is on the order of or greater than a pleat-to-pleat distance of the filter media. The distance **110** can start from as small as 0.1 of pleat tip distance up to 100 times of pleat tip distance, as illustrated in FIG. 7. The distance **110** depends on specific application (e.g., dimension, geometry, etc.) and flow rate. In some arrangements, the distance **110** is approximately 0-10 mm. In more particular arrangements, the distance **110** is approximately 6-8 mm. Across some other arrangements, the distance **110** can vary from a fraction of a pleat-to-pleat distance of the filter media to 10 or even 100 times of

pleat-to-pleat distance. In such arrangements of appropriate K-factor and separation distance, the normalized variance

$$\left(\text{i.e., } \frac{dQ}{Q} \% \right)$$

is within the range of $\pm 1.5\%$. This represents an improvement over arrangements of no mesh **104** and/or arrangements having separation distance **110** of zero, in which the variance in MAF sensor output is substantially higher. Accordingly, the mesh **104** improves the signal quality of the MAF sensor output (e.g., output signal quality to an ECM).

Various factors impact the K-factor of the mesh **104**. K-factor depends on mesh pattern, opening size/shape, thread diameter, etc. If **104** is a perforated plate, K factor depends on again, size/shape of opening, thickness and pattern of openings, etc. The pore pattern of the mesh **104** may be uniform or non-uniform. Specific impacts of different pore size and thread diameter combinations may be tested by a computational fluid dynamics (CFD) simulation. The CFD simulation is able to yield streamlines that wrap around a MAF sensor, back tracing those streamlines is able to tell what part of the conditioning device those wrapping-around-MAF streamlines come from, thus determining what part(s) on the filter panel is (are) significant to MAF performance.

Referring to FIG. 2, a front view of an exemplary mesh **200** is shown according to an exemplary embodiment. The mesh **200** may be used in an air filtration system as described above with respect to mesh **104**. The mesh **200** has a varying pore pattern and size. As shown in FIG. 2, the mesh **200** includes a first section **202** having a large pore pattern, a second section **204** having a medium pore pattern, and a third section **206** having a small pore pattern. The first section **202** having the large pore pattern has the smallest K-factor of the three sections because the air flow passes through the first section **202** with the least resistance. The third section **206** having the small pore pattern has the highest K-factor of the three sections because the air flow passes through the third section **206** with the most resistance. The third section **206** may be aligned with a MAF sensor positioned downstream of the mesh **200**. Accordingly, the air stream impacting the MAF sensor's signal quality most significantly (i.e., the air flowing through the third section **206**) is conditioned the most, while the air stream not impacting the MAF sensor's signal quality (i.e., the air flowing through the first section **202**) is conditioned the least. Accordingly, the overall K-factor of the mesh **200** is lower than if the pore pattern of the third section **206** was used throughout the entire area of the mesh **200**, which significantly reduces the restriction of such flow conditioning device.

Secondary Foam Media Arrangements

Referring to FIG. 3, an exploded perspective view of a filter assembly **300** is shown according to an exemplary embodiment. The filter assembly **300** includes a filter frame **302** and a foam media **304**. The foam media **304** is glued to the filter frame **302** as both of a filter and flow conditioner. The filter assembly **300** is placed upstream of a MAF sensor. The foam media **304** is used to both filter the air stream **306** and to condition the air stream **306**. Foam is used for the foam media **304** because foam media generally has a lower part-to-part variation that significantly reduces a MAF sensor output signal variation because foam allows only small eddies/structures in air flow to pass through. These small

eddies/structures are viscous dominant and act as "dampers" to dissipate any larger-scale turbulent structures that introduce higher amount of turbulence kinetic energy of air flow and cause higher variation of MAF sensor signal output.

However, foam media is generally less efficient at collecting smaller particles than pleated paper filter media. Accordingly, the foam media may often be oiled, which may lead to oil distribution problems in the media that cause large variations of flow pattern downstream of the foam media thereby affecting MAF sensor output and eliminating the conditioning advantages of the foam media **304**.

Referring to FIG. 4, an exploded perspective view of a filter assembly **400** is shown according to an exemplary embodiment. The filter assembly **400** is placed upstream of a MAF sensor. The filter assembly includes a frame **402**, a foam media **404**, and a pleated media **406**. The filter assembly **400** addresses the above noted drawbacks of the filter assembly **300** by adding a block of the pleated media **406** positioned upstream of the foam media **404** to filter the air stream **408** prior to the air stream entering the foam media **404**. Accordingly, the foam media **404** is a secondary media in that its primary purpose is to condition the air stream **408** (i.e., to remove the inconsistencies in the air stream **408**), not to filter the air stream **408** (i.e., not to remove particles and/or dust in the air stream **408**). Since the foam media **404** is not used to filter the air stream **408** (i.e., the air stream **408** is already filtered by the upstream pleated media **406**), the foam media **404** does not need to be oiled (i.e., a dry foam is used) such that the foam media **404** is used for conditioning purposes. The foam media **404** reduces the defects of the air stream **408** caused by the pleated filter media **406**. The foam media **404** may be secured to the frame **402** via glue or another suitable connection (e.g., overmolding the frame **402** to the foam media **404**). The pleated filter media **406** may be secured to the frame via glue or another suitable connection.

Referring to FIG. 5, a perspective view of an arrangement of the foam media **404** and the pleated filter media **406** of the filter assembly **400** is shown. The pleated filter media **406** is placed in an upstream direction of the foam media **404** with respect to the air stream **408**. The pleated filter media **406** has a first thickness **502**. The clean side of the pleated filter media **406** is offset from the first face of the foam media **404** by a separation distance **504**. The foam media **404** has a second thickness **506**. The characteristics of the foam media **404** can be adjusted to achieve specific K-factors for the foam media **404**. The K-factor of the foam media **404** largely depends on material (e.g., aluminum, polyurethane, etc.), porosity, pore size (e.g., PPI, etc.), thickness, manufacture processes (e.g., flame reticulated, etc.), and the like. In some arrangements, the K-factor for the foam media **404** is approximately 8-10. Additionally, the K-factor may be altered by adjusting various thicknesses and positioning of the foam media **402** and the pleated filter media **406** (e.g., the first thickness **502**, the separation distance **504**, and the second thickness **506** as set forth in FIG. 5). In some arrangements, a support structure (e.g., a frame or a spacer) is positioned between the foam media **404** and the pleated media **406** to maintain a separation distance **504** greater than zero.

Referring to FIGS. 10-13, close up perspective views of a 30 pores per inch (PPI) foam media are shown according to an exemplary embodiment. Referring to FIGS. 14-17, close up perspective views of a 45 PPI foam media are shown according to an exemplary embodiment. Referring to FIGS. 18-21, close up perspective views of a 30 PPI foam media are shown according to another exemplary embodi-

ment. Referring to FIGS. 22-25, close up perspective views of a 45 PPI foam media are shown according to another exemplary embodiment.

Testing Data

Referring to FIGS. 6 through 7, various testing data associated with exemplary air flow conditioning devices is shown.

Other

In other arrangements, the secondary air flow conditioning device may be a honeycomb structure or a plastic-molded 2D or 3D structure like a forest, or some kinds of 2D/3D fractal structure. For example, FIGS. 8A through 8F show views of exemplary 2D and 3D fractal arrangements that may be utilized as the second air flow conditioning device. FIG. 8A shows a front view of a circle fractal perforation arrangement. FIGS. 8B and 8C show triangular star fractal perforation arrangement. FIGS. 8D and 8E show a 3D higher order square fractal perforation arrangement involving two spaced apart perforated conditioners. FIGS. 8F and 8G show a 3D rooted square fractal perforation arrangement based on rotated squares positioned on two spaced apart perforated conditioners. FIG. 8H shows an exemplary 3D fractal arrangement having two plates with round perforations. The round perforations of FIG. 8H are offset from each other such that the holes of a given plate are offset from the previous plate in the air flow direction. In still further arrangements, the secondary air flow conditioning device may be a perforated plate. In these above listed arrangements, the K-factor depends primarily on the % open area (i.e., total "hole area" divided by the total "plate area"), in addition to the size and shape of openings, the arrangement of the openings, and the thicknesses of the conditioning devices (e.g., the honeycomb structure, the forest-like structure, the fractal structure, the plate, etc.). Additionally, in each of the above arrangements, each plate may be arranged in series with one another such that as filtered air flows through the plates, the perforations on each subsequent plate are smaller than the previous plate.

Referring to FIGS. 9A and 9B, perspective partial cutout views of a filter assembly 900 are shown according to an exemplary embodiment. The filter assembly includes a secondary conditioning device 902 placed downstream of a filter media 904 and upstream of a MAF sensor 906 in an air flow direction 908. The secondary conditioning device 902 may include any of the above described air flow conditioning devices.

As utilized herein, the terms "approximately," "about," "substantially," and similar terms are intended to have a broad meaning in harmony with the common and accepted usage by those of ordinary skill in the art to which the subject matter of this disclosure pertains. It should be understood by those of skill in the art who review this disclosure that these terms are intended to allow a description of certain features described and claimed without restricting the scope of these features to the precise numerical ranges provided. Accordingly, these terms should be interpreted as indicating that insubstantial or inconsequential modifications or alterations of the subject matter described and claimed are considered to be within the scope of the invention as recited in the appended claims.

It should be noted that the term "exemplary" as used herein to describe various embodiments is intended to indicate that such embodiments are possible examples, representations, and/or illustrations of possible embodiments (and such term is not intended to connote that such embodiments are necessarily extraordinary or superlative examples).

The terms "coupled," "connected," and the like as used herein mean the joining of two members directly or indirectly to one another. Such joining may be stationary (e.g., permanent) or moveable (e.g., removable or releasable). Such joining may be achieved with the two members or the two members and any additional intermediate members being integrally formed as a single unitary body with one another or with the two members or the two members and any additional intermediate members being attached to one another.

References herein to the positions of elements (e.g., "top," "bottom," "above," "below," etc.) are merely used to describe the orientation of various elements in the FIGURES. It should be noted that the orientation of various elements may differ according to other exemplary embodiments, and that such variations are intended to be encompassed by the present disclosure.

It is important to note that the construction and arrangement of the various exemplary embodiments are illustrative only. Although only a few embodiments have been described in detail in this disclosure, those skilled in the art who review this disclosure will readily appreciate that many modifications are possible (e.g., variations in sizes, dimensions, structures, shapes and proportions of the various elements, values of parameters, mounting arrangements, use of materials, colors, orientations, etc.) without materially departing from the novel teachings and advantages of the subject matter described herein. For example, elements shown as integrally formed may be constructed of multiple parts or elements, the position of elements may be reversed or otherwise varied, and the nature or number of discrete elements or positions may be altered or varied. The order or sequence of any process or method steps may be varied or re-sequenced according to alternative embodiments. Other substitutions, modifications, changes and omissions may also be made in the design, operating conditions and arrangement of the various exemplary embodiments without departing from the scope of the present invention.

What is claimed is:

1. A filter assembly comprising:

a support frame;

a filter media coupled to the support frame, the filter media having a dirty side configured to receive a stream of air and a clean side configured to output a stream of air that has been filtered through the filter media;

a conditioning device coupled to the support frame, the conditioning device possessing a two-dimensional fractal structure or three-dimensional fractal structure, the conditioning device positioned in a downstream direction from the clean side of the filter media with respect to the stream of air, the conditioning device offset from the clean side of the filter media by a separation distance.

2. The filter assembly of claim 1, wherein the conditioning device possesses a circle fractal perforation arrangement.

3. The filter assembly of claim 1, wherein the conditioning device possesses a triangular star fractal perforation arrangement.

4. The filter assembly of claim 1, wherein the conditioning device possesses a three dimensional higher order square fractal perforation arrangement including two spaced apart perforated conditioners.

5. The filter assembly of claim 1, wherein the conditioning device possesses a three dimensional rooted square fractal perforation arrangement based on rotated squares positioned on two spaced apart perforated conditioners.

9

6. The filter assembly of claim 1, wherein the conditioning device comprises two plates, each of the two plates arranged in series with one another such that, as air passes through the two plates, the perforation arrangement on the second plate in series is different from the perforation arrangement on the first plate in series.

7. The filter assembly of claim 1, wherein the conditioning device comprises two plates, each plate of the two plates arranged in series with one another such that, as air flow through the two plates, perforations on the second plate in series are smaller than perforations on the first plate in series.

8. A method of filtering a stream of air, the method comprising:

providing a filter assembly including a support frame, a filter media coupled to the support frame, and a conditioning device coupled to the support frame and positioned in a downstream direction from a clean side of the filter media with respect to the stream of air, wherein the conditioning device is offset from the clean side of the filter media by a separation distance;

providing a mass air flow sensor positioned downstream of the conditioning device with respect to the stream of air;

routing the stream of air through the filter media;

after passing through the filter media routing the stream of air through the conditioning device, the conditioning device possessing a two-dimensional fractal structure or three-dimensional fractal structure; and

routing at least a portion of the stream of air past the mass air flow sensor.

10

9. The method of claim 8, further comprising providing, by the mass air flow sensor, a feedback signal to an engine control module relating to a characteristic of the air stream.

10. The method of claim 8, wherein the conditioning device possesses a circle fractal perforation arrangement.

11. The method of claim 8, wherein the conditioning device possesses a triangular star fractal perforation arrangement.

12. The method of claim 8, wherein the conditioning device possesses a three dimensional higher order square fractal perforation arrangement including two spaced apart perforated conditioners.

13. The method of claim 8, wherein the conditioning device possesses a three dimensional rooted square fractal perforation arrangement based on rotated squares positioned on two spaced apart perforated conditioners.

14. The method of claim 8, wherein the conditioning device comprises two plates, each of the two plates arranged in series with one another such that, as air passes through the two plates, the perforation arrangement on the second plate in series is different from the perforation arrangement on the first plate in series.

15. The method of claim 8, wherein the conditioning device comprises two plates, each plate of the two plates arranged in series with one another such that, as air flow through the two plates, perforations on the second plate in series are smaller than perforations on the first plate in series.

* * * * *